# CLIMATE CHANGE AND THE FLORIDA KEYS

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**FINAL REPORT IN ONE FILE. JULY 21, 2010**

SOCIOECONOMIC RESEARCH AND MONITORING PROGRAM

FLORIDA KEYS NATIONAL MARINE SANCTUARY (FKNMS)

NATIONAL ATMOSPHERIC AND OCEANIC ADMINISTRATION (NOAA)

This study was funded by NOAA's Coral Reef Conservation Program

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# ABSTRACT

This research is part of the Socioeconomic Research & Monitoring Program for the Florida Keys National Marine Sanctuary (FKNMS), which was initiated in 1998.

The main report concerns the Florida Keys, after which two appendices identify key issues related to the future of the Keys over the 21st century. Four appendices follow dealing with the global environment. They are described first to put the Florida Keys into context.

**The global environment**: The threat of global climate change has grown over very few years from urgent to "red alert" according to the vast majority of climate scientists. Better climate models showing positive feedback have dramatized the evidence, but more importantly what were previously considered worst cases have moved closer to the center of the probability distribution. Global factors are therefore even more crucial than when this project was first planned in 2005.

The research is derived from the four global scenarios originally developed for the Third Assessment Report of the Intergovernmental Panel on Climate Change in 2001 – scenarios showing the consequences of taking no corrective action through climate policy. Despite their age, the scenario stories still form a reasonable framework, but the numerical implications are no longer acceptable. The new scientific consensus is that atmospheric $CO_2$ levels of 450 parts per million or more will be quite unsafe. To keep average global warming to a maximum $2^{O}C$ above pre-industrial levels means reducing the $CO_2$ from the 2009 level of 388 ppm to 350 ppm or less (Appendix 3).

Appendix 4 challenges the assumption in the IPCC scenarios that world economic growth would be unaffected by global warming – even when growing towards 4, 5, and $6^{O}C$ above pre-industrial levels. It uses a simple model to show that in some "worst" cases, and even some "most likely" cases, the world GDP could begin falling in the second half of the century – which would be unpredictably disruptive. Only the global environmental scenario B1 would produce uninterrupted economic growth through the century.

Another concern is that economic theory itself has failed to guide major government policy directions to deal with climate change and the global financial crisis. Economics needs to change some of its basic assumptions and mesh more with other disciplines (Appendix 5).

Appendix 6 discusses technologies that may help save the planet from the impact of climate change. They fall into three groups: technologies to develop renewable and other energy sources, energy efficiency, and retaining and developing land-based and coastal carbon sinks. It is also essential to keep diffusing technologies from rich to developing countries and even more to encourage the invention of genuinely new technologies in more countries, not just the United States and other first-world nations. Worldwide technological development will be vital in the fight against climate change in the 21st century, and it is encouraging that many more countries have started to develop innovative technologies.

**The Florida Keys** are the most vulnerable part of what is the mainland US State most vulnerable to climate change. The Keys are equivalent, in practice, to Monroe County. The

following points cover first biophysical factors, and then some main socioeconomic consequences:

1. The main threat is from sea-level rise, which even in the best-case scenario could inundate 38% of the current land area (in the worst case practically the whole area). More violent and frequent hurricanes will exacerbate this threat.
2. Elevated sea temperature is the primary influence on the coral reef, aggravated by acidification.
3. These factors reinforce traditional stressors including land-based pollution, overfishing, destructive fishing practices, invading species, and disease.
4. The coral cover of the reefs around the Florida Keys declined by half between 1996 to 2008. Commercial fishery landings in Monroe County showed similar declines, including reef fish (snappers, groupers), spiny lobsters, and pink shrimp.
5. Water supply is basically from outside the Keys, through aquifers. It is already being affected by saltwater intrusion, which would be aggravated by further sea-level rise.
6. Carrying capacity is a key issue for Monroe County. Partly as a result of its residential permit control, the population has been declining since 1996.
7. This trend is being intensified by structural economic and demographic change, with a large increase in the number of non-residents owning or leasing condominiums and share-type accommodation. It also shows up in the employment structure in Monroe County, with a 60% increase in the real estate sector while the main categories associated with the hospitality industry and retail trade have stagnated or declined.
8. The mainstay of the Keys economy, tourism, also remained largely static between 1995-96 and 2007-08, according to the major NOAA visitor surveys. Moreover, the tourists now tend to seek land-based rather than sea-based activities, with an increasing concentration on the historic center of Key West.
9. Finally, living close to a major population center of 5.5 million people has a multitude of consequences, most of them adding to the risks faced by the Florida Keys despite strong local and regional government action to manage the situation.

These are formidable challenges for the Florida Keys. Both the County and the Sanctuary are managing the situation as effectively as they can. The key is increasing resilience, applied primarily to the coral reef but relevant beyond. Although still difficult to manage, some control is possible over reef health, sustainability, and fisheries, local pollution, the economy and its main driver, tourism, and how to use education and outreach effectively.

These are all part of the armory of the integrated coastal and marine management system within which the FKNMS operates – multiple jurisdictions working with other federal, state and local agencies. The local community also plays a major role, with the Sanctuary Advisory Council meeting with FKNMS executives on a bimonthly basis since 1992. Local community organizations are also exerting increasing influence and support.

**Policy recommendations**: The report concludes with a set of recommendations which basically warns in the strongest possible terms against continuing a “business-as-usual” policy but ensuring that a global and national environmentally friendly regime be introduced with all possible speed. In terms of our scenarios, the choice must be “B1”. While the action to achieve this has to be global and national, the position of the Keys as America’s most threatened area suggests that the state of Florida, the FKNMS, and Monroe County are well positioned to take a strong advocacy role in the global and national policy formulation.

# ACKNOWLEDGMENTS

The origin of this project can be traced to two events, occurring more than a decade ago. In 1997, I became interested in scenario planning while pursuing another interest, resulting in the writing of four scenarios for Indonesia's future following the collapse of the Soeharto regime. Simultaneously, a life-long friend and colleague in the United Kingdom, Professor David Stout, became involved in scenario planning for different reasons, and a lively correspondence ensued. David keeps feeding a broad range of ideas from American and British newspapers and journals, which has inspired this project.

Then my son, Professor Ove Hoegh-Guldberg of the University of Queensland, wrote a seminal paper on coral bleaching in 1999 (references at end of main report), which caused Greenpeace to ask him to add the socioeconomic impacts on local communities to a review of coral bleaching in the Pacific. I was called upon at short notice to contribute this research for *Pacific in Peril* (2000), and co-wrote the scenario content with David Stout. The Greenpeace project led WWF Australia to ask Ove and me to write a joint study of the Great Barrier Reef (published in 2004), which again led to the current project. Ove naturally remains in close contact and has provided valuable advice on many sections of this report.

Living outside a small highland town west of Sydney, Australia, modern communications technology is essential. It has provided constant contact with people in the Florida Keys and worldwide, without which this project simply couldn't have been undertaken. Of course, it would have been equally impossible to undertake the project without visiting the Keys, which happened on four occasions during the extended period it took to complete the work.

My ongoing contact was Bob Leeworthy, Chief Economist in the NOAA/NOS Office of Marine Sanctuaries. Bob has been unfailingly helpful and it is nice to find a fellow economist who agrees that climate change and global crisis are forcing a major re-appraisal of economic thought.

Several other persons made truly appreciated contributions to earlier drafts. David Stout painstakingly read through one version for accuracy and clarity. TNC's Chris Bergh read a early draft of the main report and made many helpful comments. He also made an important contribution to my concept of the Keys as a higher-order ecosystem (Chapter 3.3), and his paper on sea-level rise in the Keys is central. Jim Bohnsack, John Hunt and Bill Sharp provided important advice on the biophysical Chapter 5. A distinguished Danish biotechnologist, Professor John Villadsen, read the first draft of the technology appendix in detail and made numerous constructive suggestions across a range of technologies. EcoAdapt's Lara Hansen and Alex Score (formerly WWF) read and commented comprehensively on a set of prototype policy recommendations, reported fully in Chapter 8. Needless to say, I am responsible for the actual versions, warts and all, but hardly any editing was needed and certainly no blemishes attach to Lara's and Alex's list of recommendations.

Billy Causey, Southeast Regional Director for NOAA's National Marine Sanctuary Program, and Chris Bergh, The Nature Conservancy's Florida Keys Director, have been unstinting with their support and friendship. Friendliness and helpfulness are words that comes easily to mind with people in the Keys – Dolly Garlo, Judy and John Halas, Susan Ford Hammaker, Tina and Dennis Henize, Alison Higgins, Martin Moe, Anne Morkill and George Neugent, to name but a few. More are mentioned below.

There were two reasons for visiting the Keys, apart from the obvious need to gain personal experience of the area. One was to conduct scenario-planning workshops in 2008 (and follow-up meetings a year later), with vital help from three Chamber of Commerce directors, Jackie Harder, Judy Hull, and Carole Stevens, and Craig Wanous of the Eco-Discovery Center in Key West. Jennifer Belz from Veritext provided support beyond the call of duty as well as producing painstakingly accurate verbatim records of the workshops. Debra Illes kindly made the Diving History Museum available for the follow-up meeting in Islamorada in 2009.

The second reason for visiting was to gather information on biophysical and other data. Billy Causey and his colleagues Brian Keller, Sean Morton and Scott Donahue set the stage (sadly, Brian passed away in March 2010; he and Fiona Wilmot were my first Florida Keys contacts back in 2005). Meetings were held with John Hunt and his colleagues from the Fisheries and Wildlife Research Institute (Alejandro Acosta, Rod Bertelsen, Mike Feeley, Bob Glazer, Tom Mathews, and, in absentia, Rob Ruzicka and Mike Colella who provided full data on coral cover from the CREMP program), Steve Miller and Mark Chiappone of the University of North Carolina-Wilmington, Key Largo, David Vaughan of MOTE Laboratories, George Garrett of the City of Marathon, and Patricia Bradley who provided useful background on EPA. Holly Merrill advised on State legislation matters, and Julie Cheon helped confirm my water supply notes. Jessica Bennett, market research director of the Monroe County Tourist Development Council, was helpful with statistical advice.

I also benefited from contact with NOAA's Joe Schittone and Dwight Gledhill and the Director of TNC's Insular Caribbean Program Phil Kramer, and took the opportunity to call on Gregor Hodgson at the Reef Check Foundation, Pacific Palisades, CA, while staying in Los Angeles before returning to Australia in August 2009.

The 2008 workshops themselves were attended by 60 community and business leaders from the Florida Keys, who contributed to what became a highly valuable record. They made up a true cross-section of concerned younger and older citizens, who in addition to persons already mentioned included Douglas Bedgood, Michelle Beighley, Bette Brown, Jared Brown, Bob Calhoun, Heather Carruthers, Cheryl Cioffari, Clay Crockett, Hallett Douville, Shirley Freeman, Peter Frezza, Richard Grathwohl, Doug Gregory, Audra Hill, Rick Hill, Bob Holston, Paul Johnson, Wayne Markham, Pam Martin, MaryAnn Nichols, Derek Norman, Jason O'Brien, Glenn Patton, DeeVon Quirolo, Cece Roycraft, Lila and Douglas Rudolph, Audrey and John Sahagian, Tim Saunders, Harvey Server, Carol Shipley, Rob Silk, Margie Smith, Dixie Spehar, Terry Strickland, Cal Sutphin, Ty Symroski, David Tuttle, Vicky Walker, Jodi Weinhofer, Tom Wilmers, and Shirley Wilson.

To sum up, this project has benefited from the help of a cast of, if not thousands, at least many dozens of very helpful people. Apologies to anyone I have inadvertently missed out.

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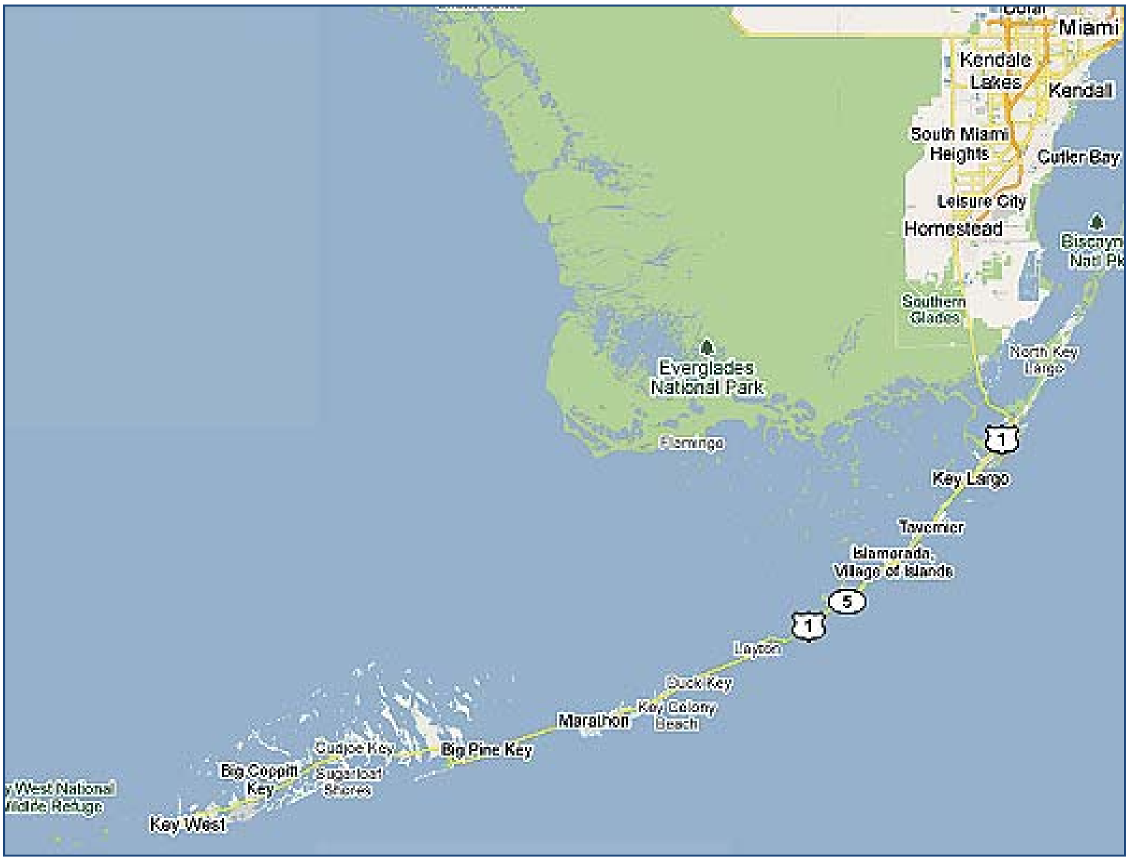
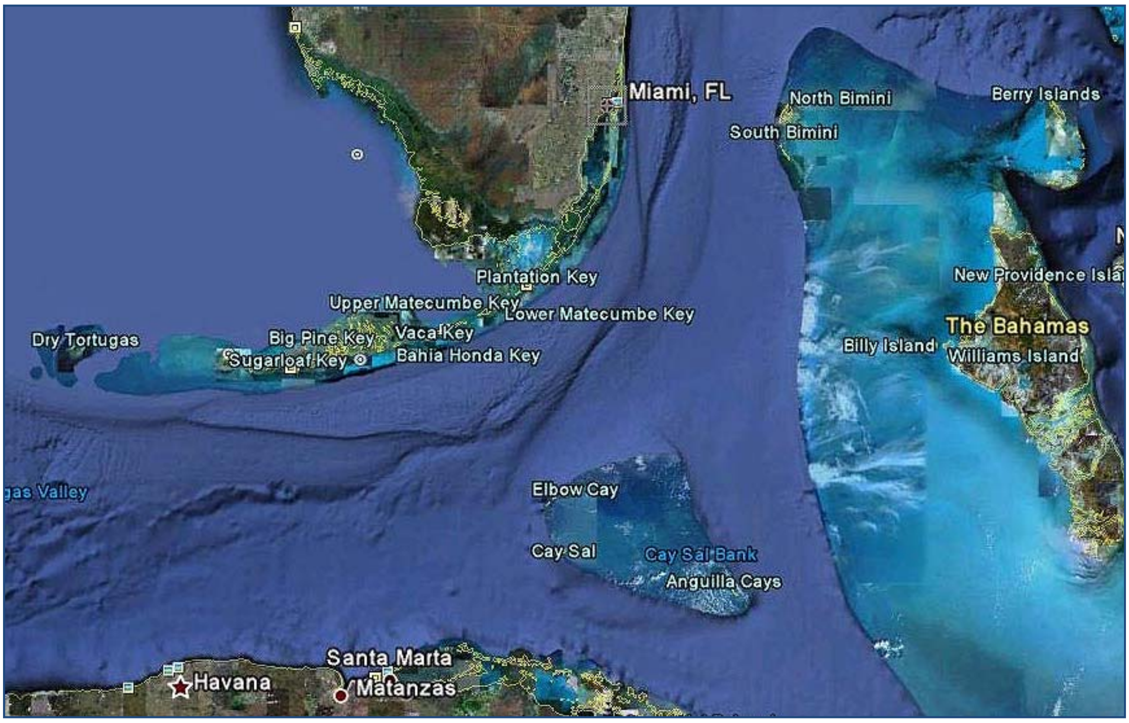
# THE LOCATION

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# MAIN REPORT

# 1 SYNOPSIS

## 1.1 TACKLING GLOBAL CLIMATE CHANGE HAS BECOME CRITICALLY URGENT

The period during which this project has been researched, since the scoping report for NOAA five years ago (Hoegh-Guldberg 2005), straddles extraordinary change. The majority of climate scientists agree that combating climate change has become much more urgent over the past five years, but more recently the world has been plunged into the worst recession since the 1930s. This has weakened the public and political will to tackle a "long-term" problem, not least in the United States which has lagged behind in the economic recovery process. New battle lines have been drawn up between those politicians and other citizens that advocate urgent action, and those who choose to see climate change as grossly exaggerated or not urgent. The global and local scenarios in Chapter 7 reflect this conflict.

The brief for the project is to study the implications of climate change in the Florida Keys with special focus on the surrounding marine area with its coral reefs. It was modeled on a study of the Great Barrier Reef in Australia (Hoegh-Guldberg and Hoegh-Guldberg 2004), which explored the available scientific, socioeconomic and environmental evidence and projected conditions to the end of the 21$^{st}$ century based on the four scenarios produced for the Third Assessment Report of the Intergovernmental Panel on Climate Change in 2001. The scenario storylines and associated numerical projections, based on research undertaken in the late 1990s, are described in the IPCC's *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000).

Funds were initially allocated in 2005 to allow the Florida Keys project to be planned in cooperation with NOAA (Hoegh-Guldberg 2005). The project subsequently received approval of the requested funding for the fiscal years 2007-08 and 2008-09. It became increasingly clear, however, that the IPCC's assumptions were falling behind: climate models had begun to incorporate large positive feedback effects and new scientific evidence showed climate change exceeding what was anticipated in the 1990s. The evidence built up dramatically that the world could no longer tolerate a large increase in greenhouse gases – on the contrary, the scientific evidence now indicates that the amount of carbon dioxide in the atmosphere should be reduced, and the average global temperature increase limited to 2$^{O}$C.

These changes forced a shift in the relative weight of global and local research for the project. It became essential to explore how the changes in the climate change outlook worked out worldwide, in contrast to the Great Barrier Reef study which basically accepted the then fairly recent global scenarios from the *Special Report on Emissions Scenarios* to concentrate more fully on the local scene. We can no longer do this in 2010, though it was assumed in the scoping report for NOAA (Hoegh-Guldberg 2005) that we could.

The updated global perspective is explained in the next section. It is hoped that one advantage of spending so much extra effort on this perspective will be its application to a wider range of problems, as well as the Florida Keys.

## 1.2 GLOBAL CHANGE

Chapter 2 summarizes four appendices to the main report which proved seminal for the development of local scenarios for the Florida Keys. They deal with elements that were less recognized or appeared less important or had not yet shown up as serious when the global scenarios were developed for IPPC's Third Assessment Report in 2001. Recent events show that these global elements have become critically important, and the appendices are essential reading for full understanding of what may happen in the Florida Keys.

The relative importance of the various manifestations of climate change is also changing. Global warming remains the determining factor but other dimensions have gained more prominence than was the case a decade ago. Sea-level rise is now seen as a greater threat in a shorter span of time; weather patterns are expected to include more frequent and probably also more violent storms, as well as more severe droughts and floods; ocean acidification was regarded as a minor factor but is now considered a major threat not just for coral reefs but for all calcareous marine organisms in the oceans (Appendix 3).

Other considerations added further to the task of coming to grips with the global situation before tackling the local prospects in the Florida Keys. Both scientists and economists have written about exceedingly uncomfortable living conditions and deteriorating economic circumstances as global temperatures climb, but no one has tried to measure it. Appendix 4 presents a simple model to introduce such projections.

Economic theory has a strong influence on the philosophy that drives government policy, not least in the 30 years leading up to the financial crisis in 2008, which was surprisingly unexpected considered the years of unusual behavior in the finance and property markets, especially in the United States. Because of this, there is a need to build economic policy assumptions into the scenarios to a greater extent than have been the case to date.

Appendix 5 contains a review of what apparently went wrong with the economics, and shows how "the greatest market failure ever", climate change, was never built properly into the dominant macroeconomic model. In the process of reviewing its assumptions, some theoretical economic thinking now appears to be connecting more with social and physical sciences such as psychology and evolutionary biology, and with the interdisciplinary complexity theory developed mainly at the Santa Fe Institute in New Mexico.

Appendix 5 concludes with a review of events since the onset of the financial crisis which have obviously influenced public and political attitudes, with an upsurge in what has been termed "climate change denialism". These events are influencing economic theory and policy as well as having a negative effect on the political will to tackle climate change, which may be expected to linger on in those scenarios that most closely resemble "business-as-usual".

The final critical area is the pace of technological change, towards renewable energy, better energy efficiency, improving carbon sinks through forestry and reducing deforestation, developing better agricultural methods, and preserving seagrass beds, mangroves, and other coastal vegetation which provide essential conduits for actively transferring carbon dioxide from the atmosphere to the ocean. Appendix 6 was inspired by the theory of technology developed by W. Brian Arthur of the Santa Fe Institute (Arthur 2009) – a theory that also helps explain the rate at which technologies get diffused worldwide, and in the process start providing a basis for true innovation in a widening range of countries.

## 1.3 NATIONAL AND REGIONAL PERSPECTIVES

While Florida and the Keys also reflect the larger US community, some vital opportunities and vulnerabilities obviously differ. This is the subject of Chapter 3. The United States provides the natural link between the broad global situation and prospects for the Florida Keys. Chapter 3 also looks for similarities in climate change vulnerability between Florida and other parts of the United States.

Both tasks were greatly assisted by a comprehensive report from the US Global Change Research Program (Karl et al. 2009), which describes the link between global climate change and the impact in the United States, and provides a regional analysis of climate change vulnerability.

On the former subject, it concludes that climate change in the United States is real, primarily human-induced, already happening, above the global average, and projected to increase with widespread effects on water, transportation, agriculture, ecosystems, and health. Thresholds will be reached, leading to large changes in climate and ecosystems.

Concerning regional similarities and differences, it notes that coastal areas including Florida and the rest of the US Southeast are increasingly vulnerable to sea-level rise and storm surges, with adverse effects very likely to be concentrated on energy and transportation infrastructure and other property in these areas. As well as sharing the adverse effect of increasing temperatures with practically every other US region, the Southeast is relatively vulnerable to climate change effects on water supply and ecosystems.

Generally, climate change will combine with pollution, population growth, overuse of resources, urbanization, and other social, economic, and environmental stresses to create larger impacts than from any of these factors alone.

## 1.4 FLORIDA KEYS OVERVIEW

Chapter 4 starts with a description of the physical, demographic and economic setting of the Florida Keys, highlighting the salient points relevant to climate change and the future of the area. The populated part of Monroe County stretches for 172 km along US Highway 1 from Key Largo in the Upper Keys, via Marathon in the Middle Keys, and via Big Pine Key and other islands in the Lower Keys, to the historic town of Key West.

The population of Monroe County is declining; growth is regulated through residential permits (Rate of Growth Ordinance, or ROGO). The economy of the Florida Keys is driven to an extraordinary extent by tourism and to a lesser extent by commercial fishing.

Apart from coral reefs, the Keys have a great variety of environmental resources, unique habitats for rare and endangered plant and animal species. The State of Florida in 1980 legislated to make the Keys portion of Monroe County an Area of Critical State Concern. Special management areas, in addition to the Florida Keys National Marine Sanctuary

(FKNMS) and other national parks, include the John Pennekamp Coral Reef State Park off Key Largo, and numerous other parks of natural or historical significance, the latter concentrated on Key West featuring a center that is basically one large historic site. Monroe County's Board of Commissioners take an environmentally sensitive approach (as evidenced by ROGO). In 2008, they instituted a "Green Initiative Task Force" to recommend practices and techniques to protect the environment and mitigate against climate change.

The bulk of Chapter 4 (Section 2) deals with eight identified key issues of importance for the future of the area, based on five scenario-planning workshops in June 2008 organized as part of this project along the Keys from Key Largo to Key West. The issues are summarized in Appendix 1 based on an edited and shortened version of the actual transcripts (Appendix 2).

The issues fall into two groups. The first group consists of issues over which it is difficult or impossible to exercise any local control. Climate change was unanimously seen as the prime threat facing the Keys; the other issues were water supply, carrying capacity, and a group of external influences including pollution from the rest of Florida and from the Midwest through the Gulf of Mexico, and potential impacts following an opening up of Cuba.

The second group of issues are considered manageable (within the confines set by the first group): reef health, sustainability and fisheries; pollution; the economy, tourism and diversification potential; and the need for continued education and outreach.

Section 3 deals with the management of the area, focusing on the FKNMS. The integrated coastal management style of the Sanctuary facilitates collaboration with local, state and federal agencies with different powers to foster compatible management strategies and practices. The Sanctuary Advisory Council is an important local source of advice, founded in 1992 early in the life of the FKNMS and meeting ever since on a bimonthly basis. The members of SAC represent nominated scientific, environmental and commercial interests which have proved their consultative influence for upwards of twenty years.

The unifying theme for the management of these resources is *resilience*, increasingly important in conditions of accelerating climate change with its effects on sea temperatures, sea level, and ocean chemistry (acidification). It is a weakness, however, that only 6% of the FKNMS area is closed to all extractive users, and mainly in the Dry Tortugas rather than along the Keys. The issues in the Dry Tortugas are not being ignored by stating that the level of protection in the Keys will be increasingly inadequate as the climate continues to change.

Institutionally and through the expertise of its management and staff, FKNMS is judged to be excellently equipped to deal with climate change, with two provisos: funding must be adequate, and more so as climate change starts to bite. Outside the realm of local control, climate change must remain controllable.

The last section of Chapter 4 describes the important role of volunteer groups and non-government organizations in the area. Some act locally, such as GLEE (Green Living and Energy Education), SFFFK (Sanctuary Friends Foundation of the Florida Keys), and special-purpose societies protecting local endangered species like the key deer on Big Pine and No Name Keys. Others started locally but have developed a broader geographical scope, such as Reef Relief. The Nature Conservancy is the leading major NGO active in the area, and the organization most closely identified with actions to build coral reef resilience.

## 1.5 BIOPHYSICAL RESEARCH

Coral cover in the Florida Keys Sanctuary declined from 12.3% in 1996 to 6.4% in 2008 according to the Coral Reef Evaluation and Monitoring Project (CREMP), which is part of the activities of the Fish and Wildlife Research Institute (FWRI), a Florida State agency. The deterioration is only the end, as of now, of a rapid development – the coral cover was probably in the order of 50% or more in the Caribbean as recent as the late 1970s, and the cover along the Keys was also much higher in decades gone by.

A different approach to CREMP's is taken by Steven Miller and colleagues in a program that have brought many new insights since its start in 1999. The approach focuses on specific issues based on randomly stratified benthic sampling rather than mapping the decline in coral cover through repeated site surveys.

The FWRI also collects detailed statistics on landings of commercial fisheries, available annually since 1986 for a comprehensive range of individual fish and crustacean species, for each county of Florida.

Yearly landings in Monroe County totaled over 20 million pounds in the late 1980s but only half that weight in 2007 to 2009. Catches have fallen for all main groups documented in Section 5.3 for Monroe County but two main species of interest here have shown the least decline: reef fish (snappers, groupers and similar species), and spiny lobsters for which almost 90% of the total catch for Florida is landed in Monroe County. A third main species, pink shrimp, has showed more than average decline relative to the State.

The chapter on biophysical research concludes with a series of notes on relevant research in the Florida Keys carried out by scientists, to be seen as examples rather than an inclusive analysis. FWRI scientists have been studying the role of seagrass beds as nursery areas for commercially important reef fishes and the similar role of hardbottom areas for spiny lobsters under threat of siltation from coastal outflows. Research into queen conch living in different positions (near-shore versus offshore) suggests that there may be a connection between climate change and reproductive behavior at different site types.

Florida Bay between the mainland and the Upper Keys is of particular importance because its proximity to the Everglades makes it a channel of pollution into the Keys ecosystem. The FWRI is instrumental in carrying out strategic planning of how to improve the status of Florida Bay.

The final research project noted in Section 5.3 is by Jerald Ault, James Bohnsack, Jiangang Luo and Steven Miller, concerning overfishing of reef fish. The situation is complex because slow-growing, long-living groupers and hogfish suffer more from exploitation than other members of the "snapper-grouper complex."

## 1.6 ECONOMIC AND RELATED INDICATORS

The total US population has grown by a modest 1.1% per annum over the past 40 years, while Florida outpaced the nation considerably up to 2000, increasing its share of the total US population from 3.3% to 5.6%. The rate of change has slowed in recent years but Florida's population still reached 6.1% of the national population by 2008, growing to 18.1

million. A massive 5.5 million live in the South Florida Metropolitan Area (Miami-Dade, Broward, and Palm Beach Counties) immediately north of the Florida Keys.

The population in Monroe County (virtually all in the Keys) increased steadily between 1969 and 1993, from 52,500 to 82,200 persons (annual growth 1.9%). Since 1993, the Keys population has shrunk every year, to reach 73,300 in 2008 (an average annual decline of 0.8%).

Florida's economic growth (3.5% pa between 1997 and 2008) outpaced the 2.7% for the US despite setbacks in 2007 and 2008. Since 1997, personal income and Gross State Product trends have been parallel, which suggests that recent personal income data at county level are representative of total economic growth. Personal income at constant prices increased by 3.2% pa between 1997 and 2008 in Monroe County despite the population decline, suggesting structural change in the Florida Keys income distribution, boosted by wealthy immigrants.

Another noticeable feature is the employment growth between 1994 and 2008 in Monroe County despite the fall in population. In 2008, 57,900 persons worked there, while the total population had declined to 73,300. This very high ratio of workforce to population can only be explained by people working in the hospitality and retail trade industries who don't live in the Keys.

These two industries are the main employers in Monroe County, but both have been employing falling numbers between 2001 and 2008. The real estate industry, meanwhile, has increased its employment considerably, providing further evidence that structural change is happening, causing high turnover of property.

One indicator of tourism activity since 1995 is bed tax statistics adjusted for inflation and a changed tax rate from June 2009. Revenue from this Monroe County tax generally increased up to 2003 or 2004 but has fluctuated around a static trend since then. Similar flat trends apply to other tourism-related indicators such as taxable tourism and recreation-related sales, which amount to about 45% of total taxable sales, rising to 48% in 2008 and 2009.

These statistics, however, tell only part of the story. The most authoritative indicators are NOAA's visitor and resident surveys of 1995-96 and 2007-08, which are the subject of Section 6.4. They show that tourism accounted 60% to total sales in both years, with the most significant structural change being a strong increase in the number of visitors using condominiums and time-share facilities rather than hotels, motels, resorts and camping facilities. Other factors included a doubling of the number of cruise ship passengers and increased spending by overnight visitors arriving by auto and air.

Passenger arrivals at Key West International Airport fluctuated after 1995, but after a peak in 2005 declined to levels not seen since 1995. Cruise ships delivered over a million passengers in Key West in 2002 and again in 2003, after strong growth. The number of cruise ship passengers has since declined to about 860,000 in 2009.

The 2007-08 version of NOAA's visitor and resident surveys finishes the section on socioeconomic monitoring of the Florida Keys, showing a decline in the average stay of tourists, and a strong trend toward land-based and away from sea-based activities. Spending by visitors for recreation purposes increased by more than would have been expected from the survey estimates of average person-trips (visits) and person-days in the Keys. As stated above, this was due to a strong increase in the number of people from outside Monroe County owning or leasing condominiums or time-share facilities in the Keys.

Importance and satisfaction ratings by tourists are increasingly associated with infrastructure facilities for tourists, while coral reef health and biodiversity are losing importance, associated with the decrease in sea-based activities. However, local residents take a stronger view on reef health than tourists.

Section 6.5 discusses the difficulties of establishing nonmarket value estimates for the Florida Keys to obtain a true total economic value. It highlights the difference between establishing project-based evaluations for reef management purposes, and developing an evaluation procedure that takes account of all stakeholder views on global climate change. The section concludes with elements of a possible approach to achieve this, basically replacing conventional willingness-to-pay measures with assessments based on greater scientific and economic knowledge than can be expected from survey respondents.

## 1.7 SCENARIOS

Section 7.1 describes how each of the four scenarios updated from the IPCC framework is treated in parallel seven-part descriptions in Sections 7.2 to 7.5. The last part (7.1.5) shows how the global scenarios were linked as formally as possible to the Florida Keys. The scenarios are the global economic growth-dominated A1, the global environmentally more sensitive B1, and the two regionalized scenarios A2 and B2, which are orientated towards economic growth and environmental considerations, respectively.

The seven-part descriptions of each scenario start with the original IPCC scenario, followed by a segment posing the question whether it would have been written differently in 2010, and a segment describing likely physical, economic and technological influences derived from Appendices 3 to 6. Part 4 links the present (2010) to the storyline to demonstrate the plausibility of the four scenarios – assuming the global storyline takes over from, say, the mid to late 2020s. Having established that this link is plausible, the scenario is then developed in Part 5 to the end of the century (with a little peep beyond). After a sketch of possible futures in the United States (Part 6), Part 7 zooms in on the Florida Keys with a set of standard projections and brief stories concluding each of the scenario descriptions. A graph shows the impact on the Keys from 2010 to 2100 according to four indicators: population, impact of sea-level rise, coral cover, and income relative to 2010.

Comparing each Part 7 on the Keys scenarios is important, especially the contrast between the global A1 scenario seen to be disastrous if allowed to run its full course, and the global B1 which allows the area to remain viable despite a 38% inundation by the end of the century (the two regionalized scenarios, A2 and B2, are each moderately more pessimistic than the corresponding global A1 and B2).

The final section, 7.6, displays a chart showing the comparison of the four scenario estimates for each of the four Florida Keys indicators. Common to all scenarios is declining population, coral cover, and income, and rising sea level. However, the extent of the deterioration differs radically between the economic "A" scenarios and the environmentally more sensitive "B" scenarios. The reason for these differences should be evident from the development of each scenario story from global to local level.

## 1.8 POLICY IMPLICATIONS AND RECOMMENDATIONS

The policy recommendations in Chapter 8 cannot be summarized and should be read in full. With climate change accelerating rapidly, the A1 path is disastrous and A2 even more so. B1 provides the best possibility though it still contains risks and its environmentally friendly approach needs further strengthening to bring the global temperature increase within the now required $2^{O}$C. The B2 scenario is less effective than B1 in preserving the Keys environment but features community involvement as a vital ingredient.

The following list is presented as a possible synthesis inspired by the specific findings of this research. It progresses from global to local perspectives:

1. There is overwhelming scientific consensus that climate change has become the most critically urgent issue of our time. There is an pressing need for effective international climate change mitigation now to limit the need to have to adapt in future.
2. Non-linear positive feedback responses in the climate system will become more frequent; intensified controlling action is urgently required. This is behind the targets to reduce greenhouse gas emissions by at least 80% by 2050, to stay below a $2^{O}$C global temperature rise and 350 ppm $CO_2$. It is not just a matter for international negotiators; constant local, state and national action is required to reinforce and re-educate.
3. It is essential, therefore, to work toward an effective and binding international agreement on emissions control, with the onus on the developed world. Define substantial points for negotiation in time for the climate change conference in Mexico in December 2010 (COP-16) and achieve binding agreement for an effective successor to the Kyoto Protocol at the very latest at COP-17 in South Africa, in December 2011.
4. An environmentally friendly global scenario exemplified by the updated version of IPCC's "B1" is vital for long-term survival, backed by a prevailing spirit of strong community involvement. Continued encouragement of environmentally sensitive policies encompassing all nations is a primary objective, whatever it takes.
5. The political process in many leading countries has temporarily lost its sense of urgency and needs a wake-up call. The United States, as world leader, needs to ensure the passage of effective climate legislation through the Senate in 2010, but political reality suggests 2011. It must happen then.
6. It is high priority to promote and fund more research into new technologies including not only renewables but also energy efficiency and the protection of rural and coastal carbon sinks, plus the international diffusion of all renewable technologies, big and small, to the developing world. Diffusion is important to get the whole planet involved.
7. The Florida Keys are the most threatened area in the most threatened mainland State in the nation. They would not survive in a "business-as-usual" scenario. This gives the Keys as a mainstream American community a unique voice in the advocacy.

8. The existing strength of the integrated coastal management philosophy forms a solid foundation for Keys-based action. The keyword is resilience.
9. Local government is an important part of the solution, setting local targets, coordinating local initiatives, pushing state and national action from “below”, and generally helping to secure that the effort to build up resilience remains “climate-smart”.
10. The Keys economy must remain viable if the community has any chance of thriving. Sixty percent of the economic activity comes from tourism, with no substitutes in sight. Tourist activity has been shifting from nature-based activities to historical tourism based on Key West. It is important to eliminate any dissonance between communities and induce maximum cooperation in their mutual interest.
11. Although mainly applied to the marine ecosystem centered on the coral reef, resilience is also a vital survival factor for other parts of the Florida Keys “super-ecosystem” – relating to natural areas, native species populations and human communities.
12. Structural change threatens the resilience of the human community in the Keys, with an influx of occasional visitors owning local property but having no other local interest. It is vital for survival to retain the strong current sense of community that remains. One way is keeping the young on side through education and outreach, encouraging them to stay, and to enlist their help working with and educating the older generation.

# 2 GLOBAL CHANGE

The outlook has changed greatly since the scenario storylines and emissions scenarios were constructed back in the second half of the 1990s (from even older information), and published in the Intergovernmental Panel on Climate Change *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000) for the IPCC's Third Assessment Report (IPCC 2001). The changes have kept up since the scoping report for the current project was written (Hoegh-Guldberg 2005), so the basic global assumptions have had to be substantially revised and have therefore taken up more time than planned when the project was first undertaken.

This is documented in Appendices 3 to 6 which should be read for full understanding of the findings for the Florida Keys (Appendices 1 and 2 deal with the local issues in the Keys). The global outlook has become more important and more complex over the past decade and has to be the starting point of any analysis of the local impact of climate change.

The four globally based appendices are summarized below. They represent a departure from the design of the Great Barrier Reef report (Hoegh-Guldberg and Hoegh-Guldberg 2004) which was the intended template for the current project. Each appendix was developed for a specific purpose to back the main report, and have their own reference sections.

## 2.1 RISKIER SCENARIOS (APPENDIX 3)

The IPCC's Fourth Assessment Report (Pachauri and Reisinger 2007) officially recognized that the causes for concern identified in the previous report (IPCC 2001) had become generally more serious. Since 2007, the outlook has deteriorated further, which is one of two main reasons for a veritable flood of new references to climate change during 2009. The second reason was the COP-15 climate change conference in Copenhagen, Denmark, in December.

The question is how the changed outlook should be reflected in the global scenario storylines, in the emissions scenarios associated with each storyline, and what are the socioeconomic implications?

The storylines themselves are sufficiently general to incorporate most changes, especially the global scenarios A1 and B1. The storylines for regional scenarios A2 and B2 are more out-of-date. This is reflected in the presentation of each scenario in Chapter 6.

Appendix 3 provides a broad review of the development of findings between the Third and Fourth IPCC Assessment Reports, with reference to possible changes to the use of scenario planning in the forthcoming Fifth Assessment Report, due in 2014 (Moss et al. 2008). The latter may take a new tack, in which mitigation strategies against the risks are apparently capable of being built into the scenarios themselves. This would be different from or at least supplementary to the current scenarios, which run to the "bitter end" to demonstrate the effects of not taking additional action during the course of the scenario period.

Climate change will disadvantage poor countries in particular. "The two greatest problems of our times – overcoming poverty in the developing world and combating climate change – are inextricably linked." (Stern 2009, p 8) The United Nations Millennium Project is important because of its ongoing monitoring of global and regional socioeconomic indicators with a focus on low-income countries. The 2008 *State of the Future Report* (Glenn et al. 2008) halfway through the 15-year project declared that humanity is “winning” on life expectancy, infant mortality, literacy, GDP per person, conflicts, and Internet use, but targets are not being met on $CO_2$ emissions and global warming, terrorism, corruption, voting populations, and unemployment (Gordon 2007).

Among the sources quoted in Appendix 3, none is more comprehensive than *Six Degrees*, by British science writer Mark Lynas (2008). Describing worlds emerging as the average temperature rises by one and then two, three, four, five and six degrees Celsius, he demonstrates on the basis of a comprehensive survey of the scientific literature existing in 2007 how ecosystems have already been affected while the temperature has risen by less than $1^{O}$C (notably coral reefs), how the scenario is likely to take on nightmare proportions at or before +4 $^{O}$C, and how positive feedback effects in the climate system may accelerate changes in global temperature after the average warming reaches the 2-$3^{O}$C range.

Major economic treatises from the UK, Australia and America weigh in with other ominous predictions if the world continues along a “business-as-usual” path, and therefore urge concerted policy action to avoid such outcomes (Stern 2006 and 2009, Garnaut 2008, Sachs 2008). It is also either stated (Meinshausen 2004, Stern 2006) or implicit in the analysis of uncertainties in the climate models that the cost of tackling climate change will escalate the longer action is delayed (Meinshausen et al. 2009).

The director of NASA’s Goddard Institute for Space Studies, James Hansen, was the first to push for atmospheric $CO_2$ to be reduced to 350 ppm or less, to be *reasonably* sure that the planet’s average temperature increase remains within a *reasonably* safe $2^{O}$C. Other advocates described in the last main section of Appendix 3 dealing with the need to set a <350 ppm target include Spratt and Sutton (*Climate Code Red*, 2008). They identify the heart of the climate change problem as the melting of the Arctic sea-ice, which they maintain can be reversed only by lowering atmospheric $CO_2$ levels to 300-325 ppm.

There was such a strong movement during 2009 in favor of a reduction to <350 ppm that it became the new position taken by scientists (supported by campaigners like *350.org*, who organized a successful global series of demonstrations for “World Climate Day” on October 24). There is increasing agreement that this position is required for humanity to have a reasonable chance of keeping global warming within $2^{O}$C of the pre-industrial level.

The final paper reviewed in Appendix 3 urges the reduction of $CO_2$ levels below 350 ppm. Veron et al. (2009) was written by a group of prominent coral reef scientists, describing the cumulative impact of rising sea temperatures on coral bleaching over the past 40 years, and how the more recently recognized threat from ocean acidification is exacerbating the situation. The paper points to probable domino effects, not only to neighboring ecosystems such as seagrasses and mangroves, but across the oceans as all carbonate-dependent taxa become affected by the acidification process.

Refer Appendix 4 for a discussion of possible reductions in economic projections as the planet warms in the less environmentally sensitive scenarios, and Appendix 5 for the estimated impact of events since late 2008: the global economic crisis, political rejection of emissions trading or cap-and-trade schemes, and the indifferent outcome of the climate conference in Copenhagen in December 2009.

## 2.2 LIMITS TO GROWTH (APPENDIX 4)

Many scientists and economists have pointed to the dire consequences of "business-as-usual" scenarios, but no attempt to quantify these predictions has been found. The IPCC scenarios themselves make no connection between a rapidly warming planet and its ability to support continuing economic growth – none of the four scenario families assumes that the connection exists. The fossil-intensive high-global-growth scenario variant, A1FI, is often used as a "business-as-usual" proxy (which is actually incorrect in scenario-planning terms). Like other IPCC scenarios showing significant global warming, it contains an implicit assumption that new technology will protect all of humankind from the effect of temperatures soaring to $3^{O}$C and more above pre-industrial levels.

There is a critical associated problem which we are stuck with for now: the scenarios use conventional economic growth measures which take no account of the depletion of resources. It is not simply non-renewable resources such as mineral deposits that are depleted (in principle these can be measured as normal statistics) – it is also the atmosphere and the world's ecosystems. The need to allow for these is great, but they cannot be expressed as conventional national accounts data. A report commissioned by French President Nicolas Sarkozy, by Nobel Prize-winning economists Joseph Stiglitz and Amartya Sen and their French colleague Jean-Pierre Fitoussi, represents a major approach to tackle these issues (Stiglitz et al. 2009).

Probability analysis continues to indicate considerable uncertainty in estimating climatic changes resulting from greenhouse gas emissions, and we are consequently facing increasing risks as atmospheric $CO_2$ levels rise. Harvard economist Martin Weitzman (2009) warns that the risk of extreme climate-related events has been rising – what he calls the "fat tail" of the probability distribution. Stern (2009) also warns against the rising danger of extreme temperature levels as stabilization levels for greenhouse gases increase.

As indicated in the first paragraph, no one seems to have quantified this, only predicted that "business-as-usual" could bring disaster. But compared with the IPPC's economic growth projections for the end of the century, which range between $235 trillion at 1990 dollar values for scenario B2 and $530 billion for the three A1 scenarios – what does "disaster" mean? Reducing global GDP by 90% at $+6^{O}$C still leaves A1 higher than the $40 trillion or so in 2010, for roughly the same global population of seven billion. The base case put forward in Appendix 4 is that global GDP reduction compared with the IPPC projections kicks in at $+1.5^{O}$C, and gradually reaches a 5% cut at +2 $^{O}$C, -50% at $+4^{O}$C, and -90% at $+6^{O}$C.

Any reduction from "what might have been" will probably always be termed a disaster, partly because economic growth has become a fetish, and also because the loss will be inequitably borne by some countries, regions and population groups rather than others. If it ever happened, however, the feeling of disaster would be exacerbated by the path of economic change, especially if the global GDP runs into long-term decline. As we are currently witnessing, economic downturns focus the public and political mind like very little else – certainly more than the threat from climate change did in 2009.

The analysis in Appendix 4 covers the four main IPCC scenarios: A1B (globalized economic growth orientation with balanced fossil and renewable power technologies), A2 (regional growth orientation), B1 (global environmental orientation), and B2 (regional environmental orientation). In addition to the intermediate A1B "marker scenario" listed above, the A1 analysis also includes its variants: A1FI (fossil-intensive) and A1T (renewables take over).

The three cases are based on Table 3.1 in the 2007 IPCC report (Pachauri and Reisinger 2007) showing the range between best and worst case projections, and the "most likely" case in between. In the "best case", with the smallest increase in warming, all six scenarios show continued growth, not drastically below the unmodified IPCC projections, but in the "most likely" case the fossil-intensive A1FI starts falling from 2080, and in the "worst case" all but one of the scenarios show economic decline: A1FI from the 2050s, A2 from 2060, the marker growth scenario A1B and B2 from 2080, and even the environmentally friendliest global growth scenario, A1T, from 2090. The *only* scenario passing the *worst case* with uninterrupted growth through the century is the global environmentally sensitive B1. Consequently, it is also the scenario least affected compared with the original estimates, showing about 20% reduction from the $328 trillion projected by the IPCC, to a level almost seven times the 2010 world GDP (which is estimated at around $38 trillion in 1990 prices).

Appendix 4 discusses the approach and gives numerical details. It also contains sensitivity analysis indicating that the basic findings stand, although naturally the detail and the methodology would benefit from more refined analysis. There is no pretence that this is more than a preliminary numerical estimate where none appears to have been made before.

## 2.3 CHANGING ECONOMIC PHILOSOPHY (APPENDIX 5)

Before the United States and the rest of the world were hit with the global financial crisis, finally triggered by the Lehman Brothers collapse in September 2008, there was a growing realization that macroeconomic theory and policies were proving inadequate. When Nicholas Stern published his *Review on the Economics of Climate Change* in October 2006, he declared greenhouse gas emissions to be the greatest *market failure* the world has known.

Economic theory associates market failure with *externalities* – transactions which have a negative impact on parties not directly involved in the transaction are defined as market failure; and with *public goods*, which can be consumed by one individual without reducing its availability to others. In traditional economic theory, the atmosphere remains a public or free good despite years of campaigning by environmental groups and others; the same applies to numerous ecosystems that are difficult or impossible to value in market terms.

Next, the current economic crisis, incredibly, struck without apparent warning despite some quite extreme behavior patterns in the banking system, housing finance sector, and Wall Street – as has been exhaustively debated since the crisis hit and spread to the rest of the world. The main response has been to blame neoclassical economic theory which provided the dominant philosophy for policy-makers during the 30 years preceding the crisis.

John Maynard Keynes, in *The General Theory of Employment, Interest and Money* (1936) identified the behavior of investors as the one component of his theoretical framework that could show destabilizing "irrational" elements if not controlled, by magnifying the fluctuations in stock prices and other financial indicators way beyond what was compatible with true economic values – what he called *animal spirits.* This is also the title of a book by Nobel Prize-winning economist George Akerlof and Yale economics professor Robert Shiller

(2009). They identify five psychological traits, or manifestations of animal spirits, which came to dominate the financial markets: *confidence*, *fairness*, *corruption and antisocial behavior*, *money illusion*, and *stories* (fully explained in Appendix 5).

The question remains: How did this happen? In a nutshell, economists following in Keynes's footsteps as early as the 1930s and 1940s forgot his animal spirits, which got crowded out by a vogue for mathematical economics and econometric models that fitted well with the rest of the Keynesian model based on "rational" economic behavior. Add to this a political philosophy growing strongly from the late 1970s and early 1980s that free markets were best left alone to kick the economy along, and the path towards the financial crisis was set.

There was another growing influence besides the recognition that the economics of climate change was not being well accommodated in the current macroeconomic thinking, and the influence of Keynes's "economically irrational" animal spirits wasn't either. That was the advent of interdisciplinary "complexity theory" mainly through the Santa Fe Institute in New Mexico, and the early role of economics in that development, throughout which the multi-skilled economist W. Brian Arthur has figured prominently as described in Appendix 5.

The main features of complexity economics (apart from involving economics in entering into closer collaboration with other disciplines) include open, dynamic, nonlinear systems, an evolutionary process of differentiation, selection and amplification providing the system with novelty, technological change generated within the system, and a fluid "biological" approach replacing a rigid 19$^{th}$ and early-to-mid 20$^{th}$ century "physics-based" preoccupation with equilibrium, stability, and determinism (Beinhocker 2006, Arthur 2000). The differences from the traditional economic model are profound (Appendix 5, Figure 4).

Looking ahead, it is likely that economics will change, at least as far as to reflect its failure to predict the irrational behavior of the financial markets that led to the crisis. The economics of climate change, however, is also concerned with "animal spirits"; the market failure called greenhouse gas emissions originated in the 18$^{th}$ century. Animal spirits profoundly influenced the technological battle between gasoline and electricity for automobiles a century ago (Black 2006). Economics is also likely to be influenced by its association with other social and physical sciences in the framework of complexity theory.

The events since the economic crisis became international with the collapse of Lehman Brothers in October 2008 has added a final dimension to the interpretation of contemporary economics, and how it may change. The economic crisis has coincided with the climate scientists becoming increasingly insistent on political action as the climate change signals got shriller, while the public and political perception has gone in the opposite direction as short-term economic and financial considerations resumed the main stage and climate change denial became the name of the game for many. This is discussed at the end of Appendix 5.

The crucial requirement according to most climate scientists and other experts is to tighten the emissions scenarios. The scientific consensus is now dominant that the world can no longer run the risk of planning for a 3$^{O}$C increase of the global average air temperature, consistent with targeting atmospheric $CO_2$ levels at 450 ppm or more. It is also abundantly clear that climate models produce variable results, and that even those indicating a mean increase of 2$^{O}$C carry risks that the rise will be higher. The uncertainty widens as the mean temperature increases, which renders the previous typical 3$^{O}$C target even more untenable.

Fortunately, the Copenhagen Accord that concluded the COP-15 conference in December 2009 acknowledged, for the first time in an official international document, that a maximum 2$^{O}$C increase above pre-industrial levels is appropriate. The corollary is that atmospheric $CO_2$ levels should be reduced to 350 ppm or less, not increased to higher stabilization levels.

The socioeconomic implications of the recent change in outlook vary from drastic to tolerable, prompting scientists to campaign more forcefully than ever for a heightened sense of urgency among politicians (Richardson et al. 2009). This is being reflected in actual climate change policy but only with a time lag, as illustrated by the failure of the US Administration to get its cap-and-trade bill through Congress, with opposition politicians being supported, indeed urged on to resist such legislation by a public that became more prone to outright denial, not just skepticism, about the existence of climate change in 2009.

Universal cap-and-trade schemes actually may have become so politically unacceptable in the United States and elsewhere that they may be replaced with arrangements to target specific sectors or individual industries. There are exactly four general ways to control carbon: reducing either population, GDP per head of population, energy intensity (energy used per unit of GDP), or carbon intensity ($CO_2$ per unit of GDP). The first two are considered to be politically unacceptable within a realistic timeframe, leaving improvements in energy efficiency (less energy per unit of GDP) and reduced carbon intensity as the avenues to follow. Both are associated with technological change, the subject of Appendix 6.

Given that economic theory has been an important influence on government financial and economic policy to date, it is plausible to expect this to continue in the future, including what has happened since late 2008. But the influence on economic policy will differ in the four scenarios, which is why the findings in Appendix 5 are critical for the scenario building.

## 2.4 WHAT CAN WE ASSUME ABOUT TECHNOLOGICAL CHANGE? (APPENDIX 6)

A driving force in complexity economics and member of the Santa Fe Institute, W. Brian Arthur, is the author of *The Nature of Technology* (2009), which provided the inspiration and theme for Appendix 6. The publication of the book coincides with a rising interest in innovation among the social sciences (Fagerberg and Verspagen 2009), including a renewed appreciation of Austrian-American economist Joseph Schumpeter (1883-1950), who maintained that technology is generated *within* the economic system – in contrast to the assumption usually made in neoclassical economics. Arthur's book develops the theory of endogenously generated technological change (with more than a nod towards Schumpeter), leading to *increasing* rates of return in a dynamically changing economic system, whereas the static neoclassical economic model shows decreasing returns.

Brian Arthur's model explains technology as a continuous, organically evolving process which bears a strong resemblance to Darwin's theory of evolution (though the selection process has to be different). Innovation doesn't arise out of thin air but is *always* based on current technology, and once an innovation is adopted, it gives rise to further change involving a hierarchy of underlying technologies. The whole pattern is subject to continuing evolution and has to keep fitting in with this evolution in conditions of constant dynamic change.

A World Bank analysis (Burns et al. 2008) found that the primary influence on technological growth, innovative and inventive activity, has been strongly concentrated in the richest countries. But it also found that new technologies are imported and adopted into the entire developing world, including the least developed nations, and at increasing speed. The evidence is strengthening that the World Bank report is becoming rapidly outdated if it ever got the message right in the first place – genuine innovation (as distinct from technologies imported from the rich countries) is swiftly becoming more prevalent (Wooldridge 2010).

It fits Arthur's model that developing countries are moving on into real innovative activities of their own: new technology may be initially imported but it will then be refined and adapted to particular applications within the countries themselves, and eventually lead to genuine innovations originating there. The result should be an expansion of the genuinely inventive base of the planet, from the richest countries through upper- and even lower-middle-income countries as we see today in Brazil and Thailand, and in the richer urban regions of China and India. Of course, it may take a long time before significant real innovative activity as distinct from importing other countries' technologies will reach the least developed countries such as Sub-Saharan Africa.

The review of technologies in Appendix 6 comprises three groups: energy technologies including renewable sources such as solar, wind, geothermal, hydro, and oceanic, plus nuclear energy (fission, fusion, and hybrid); a wide range of energy efficiency technologies of which the main one is efficient building design; and land and coastal management technologies aiming at preserving and improving carbon sinks. "Green carbon" technologies are based on forestry and agricultural activities which may not look as spectacular as the first group but may have profound effects because of their ability to be adopted in poor as well as rich nations and at small as well as large scale – furthermore biotechnology is currently advancing fast in support of these technologies, as well as becoming better accepted. "Blue carbon" coastal management technologies serve to protect mangroves, seagrasses, and salt marshes which play a vital role through their photosynthetic activities in transferring $CO_2$ into long-term storage in the deep ocean (Nellemann et al. 2009).

The findings in Appendix 6 support the statement in the *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000) that technology is a main driving force of these scenarios coupled with demographic change and economic development. However, there is no single-solution "silver bullet" allowing humanity to switch from fossil-fuel to renewable-energy technologies (Pacala and Socolow 2004). Each SRES-based scenario will of course have distinctly different combinations of technologies depending on the general storyline.

Two further points should be made. First, despite the apparent current interest of some governments, large geoengineering "solutions" to the global warming problem noted in Appendix 6 are largely dismissed, mainly because they are highly risky environmentally. They also represent, at most, steps towards mitigation, which are not supposed to be part of the scenarios. One possible technology among these options would be seeding the stratosphere with sulfur particles to deflect incoming sunlight back into space (Crutzen 2006) – but it is fraught with risks according to the main Royal Society analysis of geoengineering options (Shepherd et al. 2009). In short, options that can be grouped as geoengineering in the sense of significant manipulation of nature are not part of the scenarios.

The second point, however, is of vital importance for the understanding of climate scenarios. It reflects Stern's (2009) observation, quoted in Section 2.1, that climate change and poverty are inextricably linked. It is observed in the final sections of Appendix 6 that as well as directing the attention towards specific renewable energy technologies and particular scales of applying these technologies, beating the poverty trap also means encouraging other technologies with which the climate-related technologies interact. The introduction of microcredit in the least developed countries (starting in Bangladesh) and the current rapid adoption of cell phone and cheap computer technology are current examples, but there will be others which are likely to vary considerably between countries.

# 3 NATIONAL AND REGIONAL US PERSPECTIVES

## 3.1 LINKING GLOBAL AND LOCAL SCENARIO BUILDING

The four appendices summarized in Chapter 2 are global in scope. The first step toward the linking of global and local perspectives is to take a nationwide view of the United States. Then relevant regional differences and prospects within the nation can be explored, focusing on the Southeast along the Gulf of Mexico and the southern Atlantic coast as the final link to the Florida Keys.

Whether the scope of the perspective is global, regional, or local, these chapters concentrate on the physical evidence rather than the political, economic and commercial issues associated with climate change. It is abundantly clear from the experience of the past decade or more that the relationship between the mounting scientific evidence for accelerating climate change and the politics has fluctuated – to put it mildly. In 2009, the scientific and political paths diverged quite sharply – in 2010 there are conflicting signs as to whether the tendency is again towards convergence.

General acceptance of the urgency to tackle climate change continues to be blurred by conflicting communications and the complexity of intergovernmental and international infrastructures. For example, it is a promising sign that a majority of states (including Florida) have adopted more or less stringent, but binding, renewable portfolio standards to mandate the introduction of renewable energy, while such a standard is not visible at federal level. "Though a national policy would be nice, 50 state policies may turn about to be even better. This way, they can tailor their requirements to available resources." (Hodge 2010) Internationally, China is torn between its dependence on expanding coal-based technology and the realization that it is environmentally highly fragile. And so on.

The role of the scenario analysis in Chapter 8 is to outline different futures which highlight the risks and opportunities associated with different sets of policies, basically divided between growth-driven "business-as-usual" and environmentally friendly scenarios.

A US Global Change Research Program report (Karl et al. 2009) was transmitted to Congress by the Director of the Office of Science and Technology Policy, Dr John Holdren, and NOAA's Administrator Dr Jane Lubchenko. This was only the second such report, following nine years after the first one (Melillo et al. 2000). It contains a powerful chapter on the severity of global climate change prefaced by a graph of Antarctic ice-core data showing that atmospheric $CO_2$ never exceeded 300 parts per million for 800,000 years, but is now 30% higher than the geological-time maximum. Having grown slowly from pre-industrial levels it then started to accelerate from about 310 ppm in the late 1960s to reach the current level, increasing annually by about 2 ppm.

The global findings (Karl et al. 2009, p 12) resemble those compiled in the current project: global warming is unequivocal and primarily human-induced, and widespread climate-related impacts are occurring now that are expected to increase, affecting water, transportation, agriculture, ecosystems, and health.

The report describes national climate change and then presents a regional analysis of vulnerabilities to climate change within the United States, showing that the climate is already changing wherever we look. The following salient points were extracted from the summary (Karl et al. 2009, p 27):

- The average temperature has risen more than 2$^{O}$F (more than 1.1$^{O}$C) over the past 50 years (above the global average of 0.74$^{O}$C for the 100 years from 1906 to 2005) and is projected to rise more in the future. Using the original A2 scenario (Nakicenovic and Swart 2000) yields a projected temperature increase of 7-11$^{O}$F (3.8-6.1$^{O}$C) over the 21$^{st}$ century, and 4-6.5$^{O}$F (2.2-3.6$^{O}$C) using the global environmental scenario B1.

  The authors add that using a stabilization scenario of 450 ppm $CO_2$ has the potential of keeping the global temperature rise at or below about 3.5$^{O}$F (1.9$^{O}$C) from pre-industrial levels and 2°F (1.1$^{O}$F) above the current average temperature, "a level beyond which many concerns have been raised about dangerous human interference with the climate system." (Karl et al. 2009, pp 23-24) However, the references are two Meinshausen papers, both dated 2006. A stabilization level of 450 ppm is now considered incompatible with a 2 $^{O}$C rise above pre-industrial levels, and Meinshausen (from the Potsdam Institute of Climate Impact Research) has co-written more recent papers, including one shown in our references dated 2009.

- Projections of future US precipitation indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier. More rain is falling in heavy downpours (an average increase of about 20% in the past century, a trend that is deemed very likely to continue, with the largest increases in the wettest places).

- Extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years.

- The destructive energy of Atlantic hurricanes has increased in recent decades. The intensity of these storms is likely to increase in this century.

- The sea-level has risen along most of the US coast over the last 50 years, and will rise more in the future. Arctic sea-ice is declining rapidly and this is very likely to continue.

## 3.2 Shared Regional Vulnerabilities

The United States is divided into eight regions: Northeast, Southeast, Midwest, Great Plains, Southwest, Northwest, Alaska, and Islands (Karl et al. 2009, pp 107-148). The islands are located in the Pacific including Hawaii, American Samoa, Palau, and the Micronesian Carolinas, Marshalls and Marianas, and in the Caribbean: US Virgin Islands and Puerto Rico under the US, not counting 40 island nations with 38 million people which share similar conditions – indeed these countries are expected to be among the earliest and most impacted by climate change in the coming decades and are least able to adapt to climate change impacts (Simpson et al. 2009, p 8).

### 3.2.1 Coasts

The regional analysis concludes with a review of coastal areas (pp 149-152) which is most directly relevant for this project. A summary follows:

- Approximately one-third of Americans live in counties immediately bordering the nation's ocean coasts. Coastal and ocean activities contribute more than $1 trillion to GDP and ecosystems hold rich biodiversity and provide invaluable services.
- Intensive human use has taken its toll on coastal environments and their resources, through overfishing, the expansion of major cities and their infrastructures, and agriculture, shipping, tourism and other economic activities. More spring runoff and warmer coastal waters cause seasonal reduction in oxygen resulting from excess nitrogen from agriculture, helping to create dead zones depleted of oxygen. As well as adding nitrogen, coastal waters are polluted by phosphorus, sediments, and numerous other contaminants. Toxic blooms of algae are also becoming more frequent.
- Coral reefs have been badly damaged or are becoming overgrown with algae. Higher water temperatures and ocean acidification resulting from the uptake of carbon dioxide by ocean waters will present major additional stresses to coral reefs, resulting in significant die-offs and limited recovery. Acidification imposes yet another stress on reef-building corals, which already suffer from bleaching, disease, coastal runoff and other pollution. "As a result of this and other stresses, the corals that form the reefs in the Florida Keys, Puerto Rico, Hawaii, and the Pacific Islands are projected to be lost if carbon dioxide concentrations continue to rise at their annual rate."
- The increasing acidification threatens not only corals, but shellfish and other living organisms that form their shells and skeletons from calcium carbonate.
- Half the nation's coastal wetlands have been lost, mainly during the past 50 years.
- Sea-level rise and storm surge affect coastal cities and ecosystems; low-lying and subsiding areas are naturally most vulnerable. Coastal areas are at increasing risk from sea-level rise and storm surge, especially along the Atlantic and Gulf Coasts, parts of Alaska, and islands in the Pacific and Caribbean. Energy and transportation infrastructure are very likely to be adversely affected. Furthermore, thresholds will be crossed, leading to large changes in climate and ecosystems.
- Changing ocean currents will affect coastal ecosystems.
- Generally, climate change combined with pollution, population growth, overuse of resources, urbanization, and other social, economic and environmental stresses will create larger impacts than from any of these factors alone.

Surprisingly, the second assessment report (Karl et al. 2009) makes little or no mention of the first report (Melillo et al. 2000), although Thomas Karl and Jerry Melillo were co-chairs of both. The first report gives a valuable historical perspective on how the assessment of climate change has developed, and provides additional information which presumably remains valid in 2010. It shows that issues considered urgent today were recognized a decade ago by the leading American scientists involved in this research. The following points from the 2000 report relate to the coastal zone which is our central concern.

- **Sea-level rise**: "Global sea-level has already risen by 4 to 8 inches (10-20 cm) in the past century, and models suggest this rise is very likely to accelerate. The best estimate is that sea-level will rise by an additional 19 inches (48 cm) by 2100 with an uncertainty range of 5 to 37 inches (13-95 cm). Geological forces (such as subsidence, in which the land falls relative to sea level) play a prominent role in regional sea-level change. Accelerated global sea-level rise is expected to have dramatic impacts on those regions where subsidence and erosion already exist." (p 108).

The assessment of causes seems to have shifted from geological forces to external factors including melting Arctic ice, but sea-level rise was evidently considered a main factor in 2000. It was rated urgent then and even more so now.

- **Coastal lands at risk**: Eighty percent of all coastal wetlands (marshes and mangroves) in the US is in Louisiana, and the rest mainly along the rest of the Mexican Gulf and the Atlantic coast. In the event of a 20-inch sea-level rise, the table to the left shows Louisiana way ahead of other coastal regions concerning both wetland and dryland areas risking inundation. The numbers are estimates only, read off the published chart. Since the table was constructed for this report, the Deepwater Horizon oil spill disaster in May 2010 took place immediately off the coast of Louisiana.

**Coastal lands at risk from a 20-inch sea-level rise** (square miles, estimated from graph)

| Region | Wetlands | Dryland |
|---|---|---|
| Northeast | ~100 | ~100 |
| Mid-Atlantic | ~200 | ~700 |
| South Atlantic | ~1,200 | ~900 |
| S to W Florida | ~100 | ~600 |
| Louisiana | ~2,200 | ~1,200 |
| Rest of Gulf Coast | ~400 | ~600 |
| West | ~-200 | ~300 |

*Source: Melillo et al. (2000, p 110)*

- **Coral reefs affected by bleaching, disease, pollution, and ocean acidification**: "The last few years have seen unprecedented declines in the health of coral reefs. The 1998 El Niño was associated with record sea-surface temperatures and associated coral bleaching (when coral expels the algae that live within them and are necessary to their survival); in some regions, as much as 70% of the coral may have died in a single season. There has also been an upsurge in the variety, incidence, and virulence of coral diseases in recent years, with major die-offs in Florida and most of the Caribbean region. In addition, increasing atmospheric $CO_2$ concentrations could possibly decrease the calcification risks of the reef-building corals, resulting in weaker skeletons, reduced growth rates and increased vulnerability to erosion. Model results suggest that these effects would likely be most severe at the current margins of coral reef distribution." (p 111) The Keys are situated just within those margins.

  "Note that under model projections of the future, it is very unlikely that calcium carbonate saturation levels will provide fully adequate support for coral reefs in any US waters. The possibility of this future scenario occurring demands continued research on effects of increasing $CO_2$ on entire coral reef systems." (p 112)

  A map on the same page (reprinted in the 2009 report, p 151) shows carbonate saturation levels in American ocean surface waters. It identifies the level in pre-industrial Florida as "optimal" (>4 Ω), and the level in 2000 remained optimal on the Atlantic side but dropped to "adequate" (3.5-4 Ω) on the western side. The projection for 2050 for the whole of Florida drops to “marginal” (3-3.5 Ω). The projection also shows a drop to “extremely low” (<3 Ω) for the coastal waters – largely devoid of coral reefs – from Florida’s “panhandle” further west into the Gulf.

The description of coral reefs was made shortly after the El Niño bleaching events in 1998, and contains plenty of references to this, plus the key statement: “Some estimates of the global cost of losing coral reefs run in the hundreds of billions of dollars each year. The demise or continued deterioration of reefs could have profound implications for the US.” (p 111)

The reference to ocean acidification in a publication as early as 2000 was a surprise and worth considering in a current context. Papers published before 2000 usually “did not consider the carbonate chemistry of seawater .. to be an important factor influencing calcium-carbonate precipitation by corals because surface seawater is supersaturated with respect to aragonite.” (Gattuso et al. 1998) More recent papers like Fabry et al. (2008) suggest that the main research papers on ocean acidification as a threat to reef-building corals and other organisms date from about 2004 up to date.

The latest contribution at the time of writing, dealing with ocean acidification generally and not just confined to coral reefs, is Pelejero et al. (2010), containing the phrase that acidification is “the evil twin of global warming.” The message just keeps getting more urgent. The abstract tells it all: “Anthropogenic rise in atmospheric $CO_2$ is driving fundamental and unprecedented changes in the chemistry of the oceans. This has led to changes in the physiology of a wide variety of marine organisms and, consequently, the ecology of the ocean. This review explores recent advances in our understanding of ocean acidification with a particular emphasis on past changes to ocean chemistry and what they can tell us about present and future changes. We argue that ocean conditions are already more extreme than those experienced by marine organisms and ecosystems for millions of years, emphasizing the urgent need to adopt policies that drastically reduce $CO_2$ emissions.”

However, the seminal research paper on the threat from ocean acidification by Joan Kleypas and colleagues was published as early as 1999 (Ove Hoegh-Guldberg, personal communication). It established that since a coral reef represents the net accumulation of calcium carbonate ($CaCO_3$) produced by corals and other calcifying organisms, reef-building capacity declines if calcification declines. Coral reef calcification depends on the saturation state of the carbonate mineral aragonite in surface waters. The authors predicted then that the total calcification reduction from the pre-industrial level to 2100 could be as high as 17 to 35%.

- **Coastal erosion**: The last point to mention from the first assessment report concerns coastal management. “With few exceptions, the potential consequences of climate change are not yet being considered in coastal management. It is especially urgent to begin adaptation now with regard to development of land in the coastal zone.” (Melillo et al. 2000, p 113)

  A map of annual shoreline change, also on p 113, carries the following comment: “The areas most vulnerable to future sea-level change are those with low relief which are already experiencing rapid erosion rates, such as the Southeast and Gulf Coast." The map shows the Florida Keys as "moderately eroding" (similar to the rest of Florida apart from six relatively small areas rated "severely eroding")." In contrast, the entire shoreline along the States of Louisiana and Mississippi was classified as "severely eroding."

We note again that our comments on Melillo et al. (2000) were written before the Deepwater Horizon oil spill off Louisiana in May 2010. With 80% of the nation's wetlands, this coastline has been considered highly vulnerable for a long time.

### 3.2.2 THE SOUTHEAST AND CHARACTERISTICS SHARED WITH OTHER REGIONS

The Southeast region covers the coast from Texas (the rest of that State is part of the Southwest region) along the Gulf via Florida and up the Atlantic coast to Virginia. The Southeast extends inland as far as Arkansas, but the coastal character dominates the description in the second US Global Change Research Program report (Karl et al. 2009).

A condensed version of the threat of climate change in the Southeast reads as follows (pp 111-116): Since 1970, the annual average temperature has risen about 2°F (1.1 $^{O}$C), with the greatest seasonal increase during the winter months. The number of days per year with 90$^{O}$F (32$^{O}$C) or over will increase toward 180 or half the year, resulting in heat stress for people, plants and animals. The availability of water will decrease. Sea-level rise and hurricane activity will be among the most serious climate change effects. Ecological thresholds are expected to be crossed throughout the region leading to disruption of major ecosystems and the benefits they convey to people. Quality of life will be affected by heat stress, water scarcity, severe weather events and reduced availability of insurance to properties at risk.

The regional analysis in the report shows that among the attributes of climate change, water availability and drought, warmer temperatures, and impact on ecosystems will have universal, or almost universal, impact across the nation. Water scarcity and hotter weather will be grave concerns for the Southeast, and the region is among the most seriously affected by the threat of sea-level rise, increasing frequency and severity of hurricanes and storm surges, and impact on ecosystems. The region's coral reefs are especially vulnerable to bleaching and disease, in common with the rest of the Caribbean and the Pacific, due to warmer sea temperatures and ocean acidification.

Of the key points made in the report, two in particular deserve mention in a Florida Keys context:

*Sea-level rise and the likely increase in hurricane intensity and associated storm surge will be among the most serious consequences of climate change* . (Karl et al. 2009, p 114)

"As sea-level rises, coastal shorelines will retreat. Wetlands will be inundated and eroded away, and low-lying areas including some communities will be inundated more frequently – some permanently – by the advancing sea. Current buildings and infrastructure were not designed to withstand the intensity of the projected storm surge, which would cause catastrophic damage. .. More frequent storm surge flooding and permanent inundation of coastal ecosystems and communities is likely in some low-lying areas .. . Rapid acceleration in the rate of .. sea-level rise could threaten a large portion of the Southeast coastal zone. The likelihood of a catastrophic increase in the rate of sea-level rise is dependent upon ice sheet response to warming, which is the subject of much scientific uncertainty. Such rapid rise in sea-level is likely to result in the destruction of barrier islands and wetlands.

Compared to the present coastal situation, for which vulnerability is quite high, an increase in hurricane intensity will further affect low-lying coastal ecosystems and coastal communities along the Gulf and South Atlantic coastal margin. An increase in intensity is very likely to increase inland and coastal flooding, coastal erosion rates, wind damage to coastal forests, and wetland loss. Major hurricanes also pose a severe risk to people, personal property, and public infrastructure in the Southeast, and this risk is likely to be exacerbated. Hurricanes have their greatest impact at the coastal margin where they make landfall, causing storm surge, severe beach erosion, inland flooding, and wind-related casualties for both cultural and natural resources."

*Ecological thresholds are expected to be crossed throughout the region, causing major disruptions to ecosystems and to the benefits they provide to people.* (pp 115-116)

"Ecological systems provide numerous important services that have high economic and cultural value in the Southeast. Ecological effects cascade among both living and physical systems, as illustrated in the following examples of ecological disturbances that result in abrupt responses, as opposed to gradual and proportional responses to warming:

- The sudden loss of coastal landforms that serve as a storm-surge barrier for natural resources and as a homeland for coastal communities (such as in a major hurricane).
- An increase in sea-level can have no apparent effect until an elevation is reached that allows widespread, rapid saltwater intrusion into coastal forests and freshwater aquifers.
- Lower soil moisture and higher temperatures leading to intense wildfires or pest outbreaks (such as the southern pine beetle) in southeastern forests; intense droughts leading to the drying of lakes, ponds, and wetlands; and the local or global extinction of riparian and aquatic species.
- A precipitous decline of wetland-dependent coastal fish and shellfish populations due to the rapid loss of coastal marsh."

The first two items are directly relevant for the Keys. The third is of primary relevance for the environmentally degraded Everglades, which causes pollution across the Florida Bay to the Keys. The fourth point focuses on coastal marshes which are prevalent in mainland Florida. Other wetlands, however, are prevalent in the Keys (mangroves and adjacent seagrass beds).

The following specific points relating to Florida supplement the above picture (page references from Karl et al. 2009):

- Large urban population growth rates are occurring in South Florida, Atlanta, California, Phoenix, Las Vegas, Denver, Dallas, and Houston (p 54)
- The four most populous States, California, Texas, Florida and New York, grew from 90 million to 100 million between 2000 and 2009, 39% of the total US population growth in that period, with the strongest growth rate in Texas followed by Florida (update of Karl et. al. 2009). These States also share significant vulnerability to coastal storms, severe

drought, sea-level rise, air pollution, and urban heat island effects. Continued population growth is projected for southern coastal areas. "Overlaying projections of future climate change and its impact on expected change in US population and development patterns reveals a critical insight: more Americans will be living in the areas that are most vulnerable to the effects of climate change." (p 100)

- Over the past century, the Southeast "sunbelt" has attracted people, industry and investment. The population of Florida more than doubled during the past three decades. Future population growth and the quality of life for existing residents is likely to be affected by the many challenges associated with climate change, such as reduced insurance availability, increased insurance cost, and increased water scarcity, sea-level rise, extreme weather events, and heat stress. Some of these problems, such as increasing heat and declining air quality, will be especially acute in cities (p 116).
- Future water constraints on electricity production in thermal power plants are projected for Arizona, Utah, Texas, Louisiana, Georgia, Alabama, Florida, California, Oregon and Washington State by 2025.
- Water stress causes disputes across the country, with Georgia, Alabama, and Florida arguing over water for drinking, recreation, farming, environmental purposes, and hydropower (p 48).
- Florida's energy infrastructure is particularly vulnerable to sea-level rise and storm impacts. Most petroleum products consumed in Florida are delivered by barge to three ports. South Florida (12 counties) is served by Port Everglades, Fort Lauderdale (p 59).
- Florida and Louisiana are suffering increasing salinity of surface water resources (p 43).
- "Average autumn precipitation has increased by 30% in the region since 1901. The fall in precipitation in South Florida contrasts strongly with the regional average." But summer drought has increased since 1970 in the whole region. South Florida has experienced a nearly 10% drop in spring, summer and fall precipitation. Spring and summer rainfall is projected to decline in South Florida during this century (pp 111-112).
- The destructive potential of Atlantic hurricanes has increased since 1970, correlated with an increase in sea surface temperatures (p 112).
- Three different types of adaptation to sea-level rise are listed on p 116: (1) move buildings and infrastructure farther inland (not good advice for the Keys), (2) accommodate rising water through changes in building design and construction, such as stilts, and (3) build levees and river flood control structures. Construction is costly, however, and building levees can actually increase future risks if increased perceived safety leads to further development. Levees built for category 3 hurricanes are useless when a category 5 hits.

## 3.3 Implications for the Florida Keys

It is useful to think of the Keys as a collection of mutually dependent ecosystems – a "higher-order" or "super" ecosystem. It neatly focuses attention on the total entity that is at risk as well as the parts. The following definition owes much to personal communication with Chris

Bergh who elaborated on an original draft definition by highlighting the uneasy interactions of the component ecosystems with the socioeconomic realities:

*The Keys, in an important sense, are an ecosystem in itself, with its collection of islands complete with key deer and other threatened species, pine forests, hammocks, mangrove and seagrass communities, and the coral reefs. This uniquely interdependent collection of natural communities and species exists in an already uneasy balance with the Keys' residents and visitors. Both the social and natural components of the system are under threat, aggravated in a "business-as-usual" future.*

Much of what Karl et al. (2009) write about the Southeast applies also to the Florida Keys, and largely confirms the findings from our scenario-planning workshops in June 2008 (see Appendices 1 and 2). Adapted to the Keys, and assuming that the projections for the Southeast reflect "business-as-usual" or "BAU" rather than prompt transition to a greener society, the following list relates primarily to the impact of natural forces exacerbated by human-induced climate change:

- The background is that air and sea temperatures have been rising in the United States and will keep doing so at an increasing rate, at least in a "BAU" scenario. Taken this as read, the other items following below are listed in approximate order of importance, given that the items depend on and feed upon each other. This is reflected in the last item in the list, which refers to possible domino effects in the higher-order ecosystem defined above.

- The threat of sea-level rise profoundly affects the Florida Keys. The average elevation of the larger islands range from four to seven feet or 1.2 to 2.1 meters (Monroe County 2005). An analysis by The Nature Conservancy (Bergh 2009, p 25) shows that even according to the most optimistic IPCC scenario (an average sea-level rise of 18 cm by the end of the century), 38% of the total Keys area will risk inundation. This increases to 75% according to the most pessimistic IPCC scenario (average sea-level rise 59 cm).

  Using an assumption of a 140 cm rise in the average sea-level which looked radical when first published (Rahmstorf 2007), the estimated loss increases to 92% (95% for Big Pine Key which Bergh explored in most detail). Worst-case scenarios have moved closer to the center of the probability distribution over the past few years (Appendix 3). Stefan Rahmstorf is an acclaimed climate scientist at the Potsdam Institute of Climate Impact Research, and his assumptions are now deemed to be within the range of what could be expected.

  Bergh (2009) notes that the projections do not incorporate local subsidence (geological "sinking" of the land), which adds an estimated 10 cm over the century. On the other hand, some parcels included in the 2008 "starting acreage" may have been already fully or partly submerged. The qualifications are noted but do not alter the basic conclusions.

- Hurricanes have become more violent and more frequent. This trend is projected to continue, affecting the Keys as much as or more than any other part of the United States.

- Other extreme weather events (droughts and heat waves) will also increase in intensity.

- The coral reefs are the signature ecosystem of the Florida Keys. They are increasingly affected by coastal pollution, bleaching events, ocean acidification, and damage caused by tourists, fishing vessels, and cruise ships.
- Domino effects are likely to exacerbate conditions in this uniquely interdependent collection of ecosystems, especially in a “business-as-usual” future. The key deer is an example. Being confined largely to Big Pine and No Name Keys where the maximum natural elevation is 2.4 m above the median sea-level (Bergh 2009, p 4), the species is clearly threatened. “Median sea-level rise coupled with storm surges would inundate most of the available habitat either permanently or episodically, further threatening this endangered species.” (Janetos et al. 2008, pp 162-163)

In summary, the above items, caused by climate change aggravated by human activities, pinpoint the impact of climate change on the Florida Keys:

1. Accelerated sea-level rise
2. More powerful and numerous hurricanes and other extreme weather events
3. More hot weather and droughts
4. Further deterioration of coral reefs due to bleaching, pollution, disease, and ocean acidification
5. Deterioration of other ecosystems including mangroves and seagrasses
6. An increasing risk that the various components will unite to form domino effects on the total Florida Keys “super” ecosystem.

This leaves out external factors that will interact with those already listed:

- Population pressures from the north. The Keys are in a unique situation of having a permanent population of less than 75,000 (and shrinking), close to its carrying capacity and situated next-door to the largest population center in Florida (5.5 million) – with all that this implies in terms of competition for resources such as water and energy supplies, and having to cope with infrastructure which inevitably intrudes on local arrangements, and increased intrastate tourism and other population movements.
- Environmental pressures from the Everglades National Park, which has itself been badly degraded by the population growth in South Florida and which is causing major pollution of Florida Bay and the Florida Keys.
- Buildings and infrastructure in the Keys will become increasingly unsuitable as the climate warms and associated events start to bite. This is already happening to petroleum supplies (through Port Everglades) and water supply (salinity entering aquifers).
- Direct threats to main income sources for the Keys, primarily tourism but also fisheries.

The policy implications in Chapter 8 follow logically from the above premises, coupled with insights from a number of reports including one in which another area containing coral reefs has been adapted to the Florida Keys.

# 4 FLORIDA KEYS OVERVIEW

Following a description of the Keys in Section 4.1, the second section on issues was derived from scenario-planning workshops which the author conducted in five locations along the Keys in June 2008. The workshop proceedings, recorded verbatim, revealed a number of key issues shown in Section 4.2. The subjective descriptions based on the workshops are complemented with supportive factual information when required. Refer Appendix 1 for the identified key issues and Appendix 2 for a distillation of the original workshop transcripts.

Section 4.3 deals with the integrated coastal management of the Florida Keys National Marine Sanctuary, and Section 4.4 highlights the importance of local and worldwide non-government and voluntary organizations in the area.

## 4.1 MONROE COUNTY

### 4.1.1 GENERAL

The most detailed description is in the Monroe County 2010 Comprehensive Plan (accessible through http://www.monroecounty-fl.gov). It was prepared in 1991 in compliance with the requirements of the State of Florida to develop such a plan. For our purposes, a summary description in Chapter 2 of the Local Mitigation Strategy Plan (Monroe County 2005) provides a convenient framework.

Monroe County is the southernmost county in the United States. The total area is about 1,875 square miles (4,850 $km^2$), but large portions are submerged lands associated with parks and preserves that are under the jurisdiction of the federal and state governments. The total land area is approximately 885 square miles (2,300 $km^2$), mostly on the mainland within the virtually uninhabited Everglades National Park and Big Cypress National Preserve.

The Florida Keys themselves, which are our main concern, consist of about 102 square miles (264 $km^2$). They form an elongated chain of about 1,700 low-lying islands more than 220 miles (>350 km) in length from the southeastern tip of the Florida peninsula to the Dry Tortugas. Excluding the latter, Mile Marker 0 is at Jackson Square, Key West, and MM 107 at the northern boundary of Key Largo (that is, 172 km from MM 0). The highway known locally as the Overseas Highway connects all locations between the two (it is actually the southernmost stretch of US 1 which runs along the entire Atlantic coast from Maine south).

The Upper Keys cover the islands from Key Largo to Lower Matecumbe Key (Islamorada). The northern boundary of the Middle Keys is Craig Island, across the causeway and bridge from Lower Matecumbe Key. The southern boundary is the Seven Mile Bridge south of Marathon. The Lower Keys, with the largest number of islands, extend from Little Duck Key at the southern end of the Seven Mile Bridge, to Key West. Islands on the road to Key West include Big Pine, Summerland, Cudjoe, and Sugarloaf Keys. Big Pine Key is the second-largest island in the Florida Keys (25.3 $km^2$).

The Keys include incorporated cities (Islamorada in the Upper Keys, Marathon and the smaller Key Colony Beach and Layton in the Middle Keys, and Key West in the Lower Keys), and unincorporated areas including sizeable population centers in the Upper Keys (Key Largo, Tavernier) and the Lower Keys (Big Pine Key).

The Keys lie between the Gulf of Mexico and the Atlantic Ocean – dangling from the mainland like "hurricane bait" according to the Local Mitigation Strategy Plan (Monroe County 2005, p 2-1). The islands at the extreme ends of the chain are relatively big: Key West (13.6 $km^2$) with a natural deep water harbor and the largest population of some 25,000, 48 km-long Key Largo the largest at 31.6 $km^2$. The Keys are rocky islands and sandy beaches are not common, though some exist.

Just miles offshore on the Atlantic side of the Keys is the only living coral reef in the continental United States – the third-largest barrier reef ecosystem in the world after the Great Barrier Reef in Australia and the Yucatan Peninsula/Belize reef system.

No point in the Keys is more than four miles from water, and the vast majority much closer. The highest point, Solares Hill in Key West, is 16 feet (5 m) above mean sea level. The highest elevations of the larger islands are four to seven feet (1 to 2 m).

### 4.1.2 LAND USE AND GROWTH TRENDS

The total permanent resident population of the Keys increased slightly from 78,024 in 1990 to 79,589 in 2000 according to the ten-year US Census, but this conceals that the population increased to over 82,000 in 1993 and has fallen since. The latest estimate (2009) shows a fall to 73,165, continuous from year to year with the largest falls happening in 2004, 2005, and 2006 (long-term statistics and further discussion in Chapter 6). This contrasts with estimates on the Monroe County website showing population growth, which may be due to an increase in number of people owning property but not living there permanently, an issue mentioned in the 2008 scenario-planning workshops (see Section 4.2.7).

Growth trends in Monroe County are regulated through the number of residential permits issued – the so-called ROGO system (Rate of Growth Ordinance). "The majority of the new residential permits issued are for permanent residential use although some permanent dwellings are used by seasonal residents." (Monroe County 2005, p 2-3)

Incorporated cities administer their own ROGO allocations within the overall boundaries available for the County. Nonresidential permits are linked to the residential allocations; In effect, the area of new commercial development that may be permitted is limited to 239 square feet for each new residential permit issued (p 2-5).

### 4.1.3 ECONOMIC CHARACTERISTICS

With very little industrial and agricultural activity in the Keys, the predominant form of nonresidential development is commercial. The two primary types of commercial development are retail trade and services (which include tourism-related development such as marinas and restaurants).

In 1999, there were approximately 175 hotels and motels with a total of over 7,200 rooms, numerous rental homes, 109 mobile home/recreational vehicle parks, 6,100 individual mobile home parcels, and over 2,800 campsites. Services, dominated by hospitality (food and lodging), is the largest segment of the private sector, followed by retail trade. These industries accounted for nearly 52% of total employment, and 67% of private sector employment. For a more comprehensive and updated statistical picture, see Chapter 6 (Table 6.6 in particular).

Commercial fishing according to the County represents 7% of total employment and 9% of private sector employment. A combination of economic and natural resources factors have led to a decline in the number of commercial fishing vessels and a long-term downward trend in the total weight of the harvest. This figure cannot be comprehensively updated, as "forestry, fishing and related activities" was a confidential category in the official NAICS statistics classification, except for 2005, when the total was 1,245. Even assuming this was all fisheries, it represented only 2.2% of total employment and 2.6% of private employment – much less than reported in the Monroe County documents cited.

Two other private sector categories together accounted for about 15% of total employment: construction and finance/insurance/real estate. Public sector employment accounted for just over 20% of total employment, including the federal government and military, state and local government agencies, and utilities. Again, refer Table 6.6 for updated official statistics.

### 4.1.4 Transportation

The transportation network in the Florida Keys is unique in that a single road forms its backbone and the sole link to the Florida mainland. US 1 is a lifeline for the Keys, functioning as both highway and "Main Street." Each day it brings food, materials, and tourists from the mainland, driving the local economy. (Monroe County 2005, p 2.6)

Monroe County is also served by two airports: Key West International and Marathon, the former serving the major commercial airlines. Finally, cruise ships enter Key West as a major activity for that town. Airline and cruise ship statistics are shown in Chapter 6.

### 4.1.5 Environmental resources

The Florida Keys contain unique habitats, with many rare and endangered plant and animal species. In 1980 the State of Florida legislated to designate the Keys portion of unincorporated Monroe County and the incorporated municipalities as *Areas of Critical State Concern*. The purpose of the program is to protect the unique environment, vegetation, and natural resources of the designated area by regulating land development and other activities regarded as detrimental to the environment.

The legislature also enacted *Principles for Guiding Development*, providing for State oversight of development and changes to land use regulations, a function carried out by the Department of Community Affairs. The Department established Field Offices in Monroe County to assist in review of development permits and related issues for compliance with the *Principles*.

The following environmentally sensitive *Special Management Areas*, submitted by the Marathon office of the Florida Department of Environmental Protection, illustrate the uniqueness, geographical range and variety of the environmental resources of the Florida Keys:

- The *Florida Keys National Marine Sanctuary* is evidently in a category of its own, but the list of marine sacctuaries also includes John Pennekamp Coral Reef State Park (Key Largo) and the adjacent Key Largo National Marine Sanctuary, and Looe Key National Marine Sanctuary (five nautical miles offshore of Big Pine Key). The two national sanctuaries were established in 1975 and 1981, respectively, and were formally incorporated into the FKNMS in 1990 though they also retain a separate identity.

- *Land-based parks* nominated for their natural value comprise the Key Deer National Wildlife Refuge (Big Pine Key) and Great White Heron National Wildlife Refuge (unpopulated islands north of Lower Keys), Windley Key Fossil Reef State Geological Site (Upper Keys, including a fine tropical hardwood hammock forest), Lignum Vitae Key State Botanical Site (off Islamorada, featuring tropical hardwood hammocks), Long Key State Park (Layton, Middle Keys), and Curry Hammocks State Park (Grassy Key near Marathon, Middle Keys).
- *Four historically based parks* are Bahia Honda State Park (Lower Keys, near historic Flagler railway bridge, also including nature park and sandy beach), Fort Zachary Taylor State Historic Site (Key West), Indian Key State Historic Site (off Islamorada), and San Pedro Underwater Archaeological Preserve (near Indian Key).

### 4.1.6 Historic resources

Monroe County has about 330 locally-designated sites identified under Article 8 of the Monroe County Code as Archaeological, Historical, and/or Cultural Landmarks (available on the County's webpage). Key West's Historic Architect Review Commission has locally designated about 2,300 sites, dramatically indicating the uniqueness of that city, which adds an important dimension to the Florida Keys as a tourist destination as any visitor can see.

### 4.1.7 Green teams

It is important to add that Monroe County takes initiatives that don't find their way quickly into official publications like the Comprehensive Plan. For example, the Green Initiative Task Force was created on June 18, 2008 by the Monroe County Board of County Commissioners (BOCC). The scope of the task force is to provide recommendations to the BOCC of environmentally sound practices and techniques to protect the environment as well as climate change recommendations.

The task force has to prove itself quickly, however. BOCC has resolved that it has a sunset date of October 1, 2010.

## 4.2 Eight issues

Appendices 1 and 2 deal with issues identified from five scenario-planning workshops in June 2008. The 60 participants included senior local politicians, business people, major non-government organizations, scientists, and other opinion leaders. Ten members of the Sanctuary Advisory Council took part. Eight issues were extracted from the transcripts: four that are hard to control locally, and four potentially more manageable ones (Appendix 1). Appendix 2 distills the 70,000 words of the transcripts down to 12,000, sorted by the eight issues and the workshop location (while respecting the anonymity of the participants).

The workshop proceedings are subjective, a canvas of views generated in five two-hour meetings with as little interference as possible from the writer who acted as the workshop moderator. The purpose was to find the real issues through a free-flowing discussion, which could only be done locally and with minimal guidance to the group other than setting the stage and outlining the objectives.

Each issue is described below, based on the workshops but complemented by scientific and other evidence on particular matters, such as the impact of climate change itself, planning for water supply, carrying capacity, and so on. It is hoped that this combination of informed local opinion and factual evidence reinforces both.

*The first four issues are those hardest to control locally.*

### 4.2.1 Climate Change – The Primary Issue

Every workshop saw climate change as the underlying force and prime issue, centered on but not confined to the reef and marine environment.

- Increased sea temperatures affect coral health, causing bleaching accompanied by a range of other marine diseases. Coral cover is lost, especially on shallow reefs. It was noted that bleaching occurred 12 years earlier in the Greater Caribbean than in other parts of the world. This implies that the impact has had more time to establish itself here as the sea takes a decade or so to absorb higher air temperatures.
- On land, there is loss of endemic species of plants, wildlife and invertebrates, and invasive species take over ecological niches.
- The sea is rising much faster than projected. This has many effects, including salt water intrusion into the Biscayne Aquifer which provides fresh water for the Keys (see next section), difficulties with low-grade sewer systems dealing with sea-level rise, and a continuing need for better stormwater and wastewater facilities in Miami-Dade, Broward and Palm Beach Counties. Conditions are deteriorating for birds and fish at low tide. Ultimately, the sea-level rise could flood most of the Keys.
- Ocean acidification is exacerbating the impact of warming along the Keys. (We note that the issue has gained much impetus since 2008, when it came up in only the Islamorada workshop. See further below.)
- The jury is out on whether there will be more hurricanes, and/or more intense ones (the scientific evidence (Karl et al. 2009) shows an increase in Atlantic hurricane intensity).
- From an economic point of view, climate change will pose an increased threat to fisheries, and to real estate values. Meanwhile, climate change skeptics and deniers are still causing delays in dealing with the problems.

**These subjective statements have abundant scientific support.** The Nature Conservancy's Florida Keys office in April 2008 organized a two-day reef resilience conference in Key Largo with the theme "Coping with climate change". One example was a wide-ranging review by Keller and Precht (2008), adopting a spatial perspective on variation among coral reef systems in the Greater Caribbean and the Great Barrier Reef, a temporal perspective on the Florida Reef Tract over 125,000 years of changing climates and sea levels, and outlining the management implications: how to reduce the human impact, and anticipate further changes.

Keller and Precht were especially concerned with the "shifting baseline syndrome" occurring over the past 30-40 years:

- Shifting baseline 1: Die-off of *Acropora palmata and A. cervicornis* (Elkhorn and Staghorn coral) in the late 1970s to 1980s
- Shifting baseline 2: Mass mortality of the herbivorous *Diadema* sea urchin between January 1983 and January 1984
- Shifting baseline 3: From the first coral bleaching event in the Lower Keys in 1983 to mass global bleaching events in 1997-98
- Shifting baseline 4: Proliferation of coral diseases in the 1980s and 1990s.

Ocean acidification within a few years has emerged as a threat to coral reefs on a par with global warming itself (Hoegh-Guldberg et al. 2007). Indeed as noted in Chapter 3 it is now being dubbed "the evil twin of global warming" (Pelejero et al. 2010), referring not just to coral reefs but the oceans generally. The "twins" are of course both the progeny of greenhouse gas emissions.

The Florida Keys Sanctuary Advisory Council in August 2009 passed a resolution recognizing the threat from ocean acidification, following a presentation by the Southeast Regional Director of the National Marine Sanctuary Program (Causey 2009). The threat of rising sea levels caused by climate change has been demonstrated dramatically by Bergh (2009), using a range of projections to show the potential loss of land area and values as sea levels rise. These and other scientific contributions are taken into account in the scenarios in Chapter 7.

### 4.2.2 WATER SUPPLY

The workshops noted (Appendices 1 and 2):

- The Biscayne Aquifer is increasingly threatened by seawater intrusion, which will be exacerbated as the sea-level rises. There are cumulative effects of drought in South Florida, and fresh water is becoming the limiting factor for development. One participant referred to water as "the new oil" in terms of its actual and potential scarcity.
- Alternative sources are expensive: current treatment of wastewater in Miami-Dade County leaves it mainly non-potable, but reverse osmosis technology (which removes salt by forcing brackish or salt water through fiber membranes) may bring the quality up to potable.
- Local remedial action is important: rainwater cisterns are being reintroduced, and residents are converting septic tanks (being replaced by sewerage systems) to water storage systems. Some homes provide all their water needs, using solar energy.

**The Florida Keys Aqueduct Authority** (FKAA) channels water from a well field near Florida City in Miami-Dade County. Its history goes back to 1937, when its predecessor, the Florida Keys Aqueduct Commission, was created to obtain an adequate sanitary water supply for the Keys. In 1939, the US Naval Air Station near Key West was re-activated and a military build-up started. This required a large additional supply of water, which led to an agreement between the Department of the Navy and the Commission. The Navy acquired 360 acres near Florida City in Miami-Dade County, drilled wells and constructed a filtration plant. The pipeline had a capacity to carry 3 million gallons per day (MGD), of which the naval base required two-thirds, leaving one-third for the Commission.

The capacity has been progressively increased, especially since FKAA took over from the Navy in 1976. The Authority currently operates three water treatment facilities to meet its water supply needs. Groundwater from the main freshwater 130-mile Biscayne Aquifer (located 30 to 100 feet below the surface) and the deep brackish-water Floridian Aquifer 1,700 feet down is lime-softened at the water treatment plant near Florida City. Seawater from wells is desalted using reverse osmosis membrane technology at two emergency water supply plants at Stock Island and Marathon (FKAA 2006a,b). They are capable of supplying 3 MGD, but costs are high so these plants are used in emergencies only.

The Biscayne Aquifer is under increasing strain because it also serves as the principal source of fresh drinking water supply for all of Miami-Dade, Broward and Palm Beach Counties. The rapid population growth and rising water demand in Southeast Florida has forced the South Florida Water Management District to put strict restrictions on the quantity of water that users can continue to withdraw from the Biscayne Aquifer, especially during the dry season when the aquifer receives less recharge from rainfall. FKAA's well field is particularly vulnerable to withdrawal restrictions because of its close proximity to the Everglades National Park to the west, and to the saltwater intrusion line to the south and east.

The withdrawal restrictions mean that an alternative water supply must be secured in order to augment the current water treatment capacity of the system, as is happening with the construction of aquifer storage and recovery (ASR) wells deep enough to reach the Floridian Aquifer. These moves were endorsed by the South Florida Water Management District and the Department of Environmental Protection as a viable alternative source of water supply.

In support of this initiative, FKAA filed the appropriate documents and received all required regulatory permits needed to construct an ASR well with an estimated depth of 1,350 ft. The volume of water yielded during each "recovered" cycle is treated and blended with water extracted from the Biscayne Aquifer, thus increasing the output of the water treatment system without exceeding the withdrawal allocation permit of the Biscayne Aquifer.

In January 2010, a reverse osmosis plant was opened at the main FKAA treatment plant at Florida City to supplement the 17 MGD which is the limit that FKAA can draw from the Biscayne Aquifer. The new plant draws on the brackish waters of the Floridian Aquifer. It is capable of adding 6 MGD to the maximum 17 MGD available through the Biscayne Aquifer. Using reverse osmosis to remove salt from brackish water is considerably less expensive than to remove it from sea water (Wadlow 2010).

FKAA faces significant challenges in meeting the projected water demand for the next twenty years. Functional population projections (residents plus the population equivalent of tourists) used to develop water consumption needs to 2025 indicate that the daily production rate must be increased from 23.79 MGD to 29.11 MGD (FKAA 2006b). This increase in production capacity will also require significant improvements to the water treatment system.

These initiatives have important links to the recovery strategy for the waters of the Everglades National Park, with which the water supply program is intimately connected. The once vibrant Florida Everglades is now a dying ecosystem (FKAA 2006a), with a vast reduction in its natural water flow, combined with loss of 50% of its wetlands and other factors related to South Florida's rapid growth. The US Army Corps of Engineers in partnership with the South Florida Water Management District have developed a plan to save the Everglades. The Comprehensive Everglades Restoration Plan describes a series of projects to take place over more than 30 years to restore the ecosystem, largely focusing on improving water deliveries.

### 4.2.3 CARRYING CAPACITY

It was noted in the workshops that the carrying capacity study (URS Corporation 2002) is based on an endangered species model including hammocks connectivity and endangered species mainly in the Lower Keys (Key deer, Lower Keys marsh rats, and others). Relevant other documentation includes the 20-year Monroe County 2010 Comprehensive Plan, adopted in 1993. To curb excessive growth occurring in the 1980s, the Rate of Growth Ordinance (ROGO) was introduced in 1992 to limit the number of building permits, and restrict building heights. The aim was to bring the population in line with the mandatory time for hurricane evacuation.

Together with its non-residential counterpart, NROGO, ROGO controls growth throughout Monroe County, but while it was effective in this, causing new building permits to fall to about one-fifth of the level in the 1980s, it became too complex. A Tier System introduced in 2006 greatly simplified the ROGO process and introduced a method for directing growth to acceptable areas and allowing conservation in areas of environmental sensitivity on Big Pine Key and No Name Key, the main habitats of the endangered Key deer (*Odocoileus virginianus clavium*), remnant descendants of an original colony of white-tailed deer (*O. virginianus*). These systems are explained in various Monroe County publications, including a “layman’s guide” (2006).

*Population issues noted in the workshops (directly or indirectly associated with carrying capacity) indicated a variety of concerns for the future, many of which are borne out by recent statistics and other research including analysis of the NOAA visitor survey in 2007-08*:

- Just too many people (locals and visitors) for too small an area
- Losing our workers, and volunteers
- Few young people return to work in the Keys
- Population projected to double in size in Florida by 2060 (Zwick and Carr 2006)
- Whether to discriminate between types of residents and visitors to attract to the Keys
- Litigation costs are high if trying to prevent people from coming here
- Keys may become almost entirely populated by the wealthy
- Transient community – people living here part-time only
- Special issues in Key West: Dilution of unique heritage through unbridled development; drastic community change could happen; newcomers’ lack of understanding of heritage.

**The Florida Keys carrying capacity study** (URS Corporation 2002) used a "carrying capacity analytic model" (CCAM) consisting of a number of interrelated modules:

- *Socioeconomic impacts*: Permanent, seasonal (staying 30-180 days a year), and transitional (less than 30 days) population adding to the total "functional" population; number of dwellings; tourism numbers and associated infrastructure and earnings.
- *Fiscal impact*: additional government capital expenditure on improving the US 1 highway, wastewater, stormwater, land acquisition, and restoration.
- *Infrastructure impacts*: potable water, traffic, hurricane evacuation.
- *Terrestrial ecosystems and species*: Habitat loss and fragmentation (loss of half the habitats existing prior to development; fragmented into smaller patches, averaging five acres now compared with 100 acres prior to development; number of upland patches up from 160 in 1800 to 200 in 1945 to 500 in 1995. Species richness: Key deer tripled in numbers since 1970s in their small area (mainly Big Pine and No Name Keys).
- *Marine ecosystems and species*: water quality, water conservation, pathogens in the marine environment, effects of nutrients on benthic communities, direct human impacts on marine resources (propeller scarring, snorkeling and diving impacts on coral reefs, recreational fishing).

Carrying capacity was defined as the maximum level of development that could be supported without damage to the natural and human resources of the area. Some of the main conclusions were (Chapter 5):

- *Terrestrial ecosystems and species*: Land development has displaced 50% of upland habitats and lost areas of saltwater headlands. More than 90% of remaining uplands are distributed in patches of 10 acres or less. Loss of key ecological functions are estimated to happen below 13 acres. Terrestrial habitats show concentrations of tropical, Caribbean and temperate species unique in the US: over 100 species occur only in the Florida Keys.
- *Human infrastructure*: Six future scenarios all call for small growth in population and number of dwellings (less than 10%, mostly less than 5%) over the 20 years following the study. However, even small growth may place stringent demands on some infrastructure capacities: expanding the capacity of the US 1 highway; water withdrawals growing faster than population requiring alternative water supplies including more reverse osmosis desalination plants.
- *Socioeconomic impact*: The study suggests that the small increases in the permanent population "are unlikely to affect the overall socioeconomic structure of the Florida Keys" (p 120). (*This was **not** the view of the workshop participants summarized above under population issues – a view which seems closer to the truth, subjective or not.*) Also, according to the carrying capacity report, an increase in visitor numbers assumed in one of the scenarios would impose additional demands on tourist-related land uses, water supply, and recreational opportunities.
- *Fiscal impact*: In contrast to a generally modest impact due to growth, "the six future scenarios would result in a disproportionate increase in government expenditures with

respect to the projected increase in population. Per capita annual expenditures are likely to increase in all the scenarios, creating immediate pressure for government to increase revenue. Tax increases on both the local population and visitors would likely occur." (p 121)

- *Marine ecosystems and species*: "The existing data are insufficient to establish quantitative, predictive relationships between land use or development and the marine environment. However, there is plenty of evidence of human effects on the marine ecosystems and species in the Florida Keys." (p 121) The evidence includes seagrass scars, boat groundings, beach closures, coral collisions, and poor water quality in the canals.

Suggested guidelines include preventing encroachments into native habitats, already badly damaged; combining and intensifying the many existing programs (land acquisitions, wastewater and stormwater plans, the ongoing research in the Sanctuary, and restoration work); focusing on redevelopment if further development is to occur; and increasing efforts to manage habitats to preserve and improve the ecological nature of the remaining terrestrial ecosystems.

The carrying capacity study was criticized in a National Research Council report (NRC 2002) on a number of grounds:

- The socioeconomic impact of tourists was not estimated separately, which precluded modeling of their activities, such as boating, fishing, and diving. The socioeconomic module therefore accounted too simplistically for tourism, as well as having no useful indicators of quality of life.
- The human infrastructure module only dealt with traffic and hurricane evacuation times.
- The marine module did not have good data and would require almost complete revision (the terrestrial module was more successful in securing data).

In conclusion: "Endeavors such as CCAM tend to obscure significant environmental uncertainty and project an unrealistic understanding of complex environmental issues. The CCAM has important information particularly when modules are based on good and reliable scientific data. But in the end decisions to be made will be social not scientific." (p 4)

The carrying capacity study, nonetheless, has been influential in setting boundaries for the growth potential of the Florida Keys, limited by resource constraints. In fact, the population has continued to fall, rather than showing small increases, though this may be due to the influence of the strongly increasing non-resident ownership of condominiums and time-share premises.

The carrying capacity study has been in existence for almost a decade, and prospects must now be seen also in the light of a more severe climate change outlook. This and the apparent failure of the carrying capacity study to acknowledge that the demographic and socioeconomic structure in the Florida Keys is changing means that a reappraisal is required. This project cannot provide this in any detail, but it can at least indicate in a general way how structural demographic and socioeconomic change may affect the local scenario assumptions in Chapter 7.

### 4.2.4 Other external influences

Three main groups of external issues arose from the workshops, mainly as threats rather than opportunities. The first group is associated with the rest of the United States and resulting pollution of the Gulf of Mexico, the second more specifically with the rest of Florida including pollution of Florida Bay and the Keys from a degraded Everglades ecosystem, and the third with Cuba:

- Red tide from Mississippi, runoff; flooding Ohio and Mississippi Rivers; algal blooms in Gulf. (The workshops might also have commented on President Obama's decision to allow oil and gas exploration in the Mexican Gulf and elsewhere along the US coast, and the Deepwater Horizon oil spill off Louisiana only a month after his announcement – except it only happened in 2010.)
- Influences from the rest of Florida include stormwater from the Everglades influencing water quality in Florida Bay and elsewhere along the Keys; pollution from a Florida sugar cane industry expanded for biodiesel; pressures from densely populated counties to the north including new development projects in Miami-Dade County; lack of control over ocean outfalls to the north. One specific problem was that even if US 1 was upgraded in the Florida Keys, effective hurricane evacuation would still depend on the roads north being able to handle the impact of a strongly growing population around Miami.
- The main potential threat from Cuba was commencement of offshore drilling, with the main threat to the Dry Tortugas. Mixed opportunities and threats were associated with the opening up of Cuba for tourism: competition from Cuban dive spots, potential opportunities to cooperate on ferry and air transport, and sharing destinations with Cuba.

Some of the issues above are dealt with in the scientific literature. For now they flag a number of concerns that have to be managed.

*The second set of issues identified from the workshops falls into the "more manageable" category. They also provide an opportunity to focus on the most important features for future planning: the resilience of coral reefs, their vulnerabilities, and the critical importance of marine sanctuaries, all of which will have a strong impact on the local scenario building in Chapter 7.*

### 4.2.5 Reef health, sustainability, and fisheries

The workshops identified three main factors, and the overlap with the first issue, climate change, is clear from the outset. But this looks at what is locally possible. The descriptions in the three main groups provide a generalized picture of local opinion leaders' concerns:

*The major factor is warming*, with the following positive comments:

- Local action is possible towards environmental sustainability, the main long-term goal. There is important ongoing work on coral reef resilience (the dominant theme further discussed below), on continued sanctuary development, and on efforts to restore the major reef-building Elkhorn and Staghorn corals (*Acropora palmata* and *A. cervicornis*).

- Martin Moe supported by MOTE Marine Laboratory has worked to restore the herbivorous long-spined sea urchin (*Diadema antillarum*) as a lost link in a chain keeping the reef ecosystem healthy. Before it succumbed to disease in 1983, this urchin maintained the ecological balance between coral and macroalgal growth on Atlantic reefs. Three years of work to develop a process for mass culture of the urchin finally proved successful in 2009, and the task is now to return it in ecologically functional numbers:

  "If we could produce large numbers of healthy juvenile *Diadema* in hatcheries in a variety of sizes and ages, with appropriate genetic background and high health, and learn to stock them responsibly and effectively, it would be an exceptional tool for research and development projects for ecological restoration on selected coral reef areas. In fact, it may be the only effective biological tool available for ecological restoration of Atlantic coral reefs." (Moe 2009).

  The Coral Reef Evaluation and Monitoring Project (CREMP) records the number of stations in its coral reef watch that observe *Diadema antillarum.* While still a small fraction of the total 113 CREMP stations, the number observing the urchin increased from four in 1996 to 13 in 2005 (but then declined to nine in 2006) (Callanan et al. 2007). This is not an explosive recovery in the natural environment, but at least there appears to have been some progress.

The following points are listed for additional perspective:

- Some senior members of the Florida Keys community commented on the great deterioration of the reefs that has occurred since the 1950s-1960s ("shifting baselines").
- These reefs are more vulnerable than the Great Barrier Reef due to their proximity to the coast.
- Bleaching events here preceded similar events elsewhere by at least 10 years.
- Reef health is vital to reef use, including fisheries.
- "We all need to get on the bandwagon to promote reef health", like local organizations GLEE (Green Living and Energy Education) and SFFFK (Sanctuary Friends Foundation of the Florida Keys).

*Water quality:*

- Restoring the Everglades is essential for fisheries and drinking water supply (increasingly exposed to saltwater intrusion).
- The Keys act as a turbidity barrier. Tumors in turtles, lobsters, shrimp, and fish are associated with the connectivity of systems: the water quality problems are broader than they used to be. The theory is that outflow of organic matter (hormones, pharmaceuticals), mainly from cruise ships, causes the problem (aided by outflows from septic tanks along the Keys). The greater abundance of coral in the Upper Keys compared with Marathon may be due to fewer openings from the bay side to the ocean side – so the islands actually act as a turbidity barrier (Appendix 2).

*Fisheries*:

- Monroe County is a major commercial fisheries area (especially for groupers, snappers and other reef fish, and spiny lobsters, as shown in Chapter 5).
- The overriding issue is how to support fisheries but to limit the damage from fisheries to sensitive ecosystems and reefs: prop-dredging, anchor damage, lines trapped around coral – "reef death from a thousand cuts," as one participant put it.
- *Commercial versus recreational fishers*: issues with division of fish stock; access problems for commercial fishers due to rich recreational fishers; in contrast to recreational fishing, commercial fisheries are strictly regulated; declining fish size due to overfishing; the long-term increase in fishing pressure will continue after the current recession; need to educate some commercial fishers how to conduct good businesses.
- Associated issues: Excessive use of the Global Positioning System (GPS) to identify catches. One important benefit of zoning is increased yield in unprotected areas.

**Resilience and reef health:** The subjective workshop observations are again well supported. The Nature Conservancy in April 2008 organized a major reef resilience conference in Key Largo, *Coping with Climate Change*, sponsored by the Florida Reef Resilience Program (FRRP). As well as providing a forum for managers to exchange experiences at roundtables and other events (see FRRP 2008), the three-day conference was addressed by a number of scientists, sanctuary managers and others. All presentations can be found at http://frrp.org.

FRRP is a public and private partnership that brings scientists, reef managers and resource user groups together to develop strategies to improve the health of Florida's reefs and enhance the economic sustainability of reef-dependent commercial enterprises. Figure 4.1 provides a simple illustration of the concept, from one of several versions presented at the resilience conference.

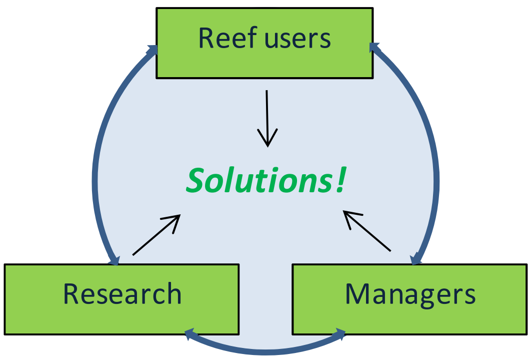



*Figure 4.1:*
*Working together on resilience strategies*
*Redrawn from Score (2008)*

Ocean warming and acidification cannot be effectively addressed at local level alone, but reef managers and reef users can help make coral reefs and the human communities that depend on them more resilient to climate change-related stresses. FRRP has employed the concept of resilience since 2005 to identify coral reefs that will be best able to withstand climate change impacts, and to develop resilience-based reef management and reef use strategies that will maximize protection of resilient reefs and enhance the viability of those that are less resilient (Bergh 2009, p 29).

No one at the reef resilience conference disagreed that climate change is real, coral reefs are imperiled, and climate change is already affecting reefs. Furthermore, NOAA has been cooperating closely for several years with the Great Barrier Reef Marine Park Authority

(GBRMPA) in Australia, initially through its Coral Reef Watch and its then Ocean and Coastal Conservation Policy Advisor, Roger Griffis. NOAA and GBRMPA agree on climate change.

Paul Marshall, GBRMPA's climate change director, presented the conference with the message that the Great Barrier Reef is being affected by climate change, that action is urgently required with a principal strategy to maximize resilience, and that GBRMPA is taking action. He noted that the Australian reef ecosystem is being imperiled especially by rising sea temperatures and sea levels, and by changing ocean chemistry – though also by rising storm frequency and intensity, precipitation, drought and runoff, and changing circulation (Marshall 2008). An 800-page vulnerability assessment covering all species, species groups and habitats from coast to ocean should leave no one in doubt that the Great Barrier Reef World Heritage Area is "under threat as never before" – to quote the foreword to that volume (Johnson and Marshall 2007).

The coordinator of the NOAA Coral Reef Watch agreed with the assessment (Eakin 2008) and presented detailed evidence of rising thermal stress in corals, before recommending the Australian reef managers' guide (Marshall and Schuttenberg 2006), the publication of which was supported by NOAA and the International Union for Conservation of Nature (IUCN). He even hinted at "a reef manager's guide to ocean acidification," though this possibility may still belong to an uncomfortably distant future.

Eakin commended a number of other efforts supporting the management of coral reefs, including the Florida Keys Coral Bleaching Early Warning Network, Bleachwatch, a cooperation between MOTE Marine Laboratory and the FKNMS. It is modeled on a similar program in the Great Barrier Reef, established in 2002 during a mass bleaching event.

The Florida Keys version of Bleachwatch was the subject of a special presentation at the conference (Bartels and Walter 2008). The early warning network has two streams:

- Environmental monitoring of climate, remote sensing, and in-situ data from four reefs along the Keys and Pulaski Shoal west of Key West (MOTE and FKNMS/NOAA)
- The Bleachwatch observer network (MOTE, FKNMS and TNC).

The outcome is synthesized data and observations, and reports on current conditions to FKNMS/NOAA.

The observer network has three components:

- Community: Anyone, including residents, tourists, pilots, "any eyes on the water"
- Professional: Dive operators, dive clubs, marine life collectors and others, after completing a short training course
- Scientific: Federal, state, private and academic researchers (FKNMS Damage Assessment and Restoration Program (DARP) and other staff, Fish and Wildlife Research Institute (FWRI), continuing scientific surveys; FRRP, others).

In 2007, the Florida Keys Bleachwatch received 264 reports from >50 volunteers reporting (out of >100 trained to date). At least 25 volunteers reported every two weeks, and eight current conditions reports were distributed. It reported "great relationships with several organizations."

A study of coral resilience in the face of global climate change (Woesik 2008) stressed the need for better understanding of the processes for coral cover change: connectivity, recruitment, post-settlement mortality, growth, heating, fragmentation, mortality. Woesik concluded:

1. Projected changes in climate may drive temperature and seawater chemistry to levels outside the envelope of modern reef experience.
2. Coral tolerance during periods of high sea surface temperatures depend on local light conditions, water flow rates, colony size and shape, and species.
3. Some reef organisms will adapt to climate change more than others – some will be winners, some will be losers, a point also made by Score (2008) and others.
4. Increase desirable states by increasing capacity of the *system* to absorb disturbances maintaining key processes.

In conclusion, resilience has three components (Score 2008). *Resistance* is the ability of corals to resist negative impacts of stress. *Tolerance* is the ability of corals that suffer negative impacts to rebound and live. *Recovery* means that dead corals are replaced by live ones rather than macroalgae. She recommended five general management strategies and one set relating to fisheries management in the interest of resilience:

1. *Education, outreach, awareness and appreciation strategies* including communication of key reef resilience and climate change themes
2. *Research and monitoring strategies* including better integration of DRM (disturbance response monitoring) with other ongoing and new research and monitoring
3. *"Best reef use practice" strategies* (for example for diving, and fishing on and near reefs)
4. *Management strategies that don't need new regulation* (navigation aids, mooring buoys, law enforcement focused on resilient reef areas and highly vulnerable but valuable reef areas, and using FKNMS authority to close sick reefs to the public)
5. *New regulatory strategies* including general (rotate closures, boating licenses, regulations to reduce GHG emissions), tourism-oriented (required environmental education, best practices license), zoning-oriented (marine zones governed by resilience concepts), coastal construction-oriented (timing of sediment producing construction, no dredging, no beach renourishment), water quality-oriented (centralized sewer, storm water treatment, pesticides), and law enforcement (focus on resilient reefs, increase presence, undercover inspectors)
6. *Fishing management strategies* (reduce ghost traps; develop a reporting system for boaters to notify trap fishermen and authorities of accidentally cut trap lines; fully implement the lobster trap reduction plan).

### 4.2.6 Pollution

*Workshops on impact on reef from the north*:

- Coral bleaching, associated disease history, and land-based pollution and other influences. How to maximize coral resilience in the face of pollution from external sources – major mainland rivers and the Everglades.
- Turkey Point Nuclear Station (Biscayne Bay, 25 miles south of Miami) is being expanded. It uses Bay water for cooling but the question was raised where it flows from the cooling canals. (According to the Florida Power and Light website a separate supply of water that cools the turbine steam supply for reuse comes from a system of 36 interconnected canals. The canals act like a giant radiator to cool the water in a two-day, 168-mile journey before it is circulated back to the condenser for reuse.)
- Outfalls from major cities in the north are mandated to shut down by 2025, but funding is a problem. On April 30 2008, the Florida Legislature passed a bill to end dumping of partially treated sewage onto the reefs of Southeast Florida. Wastewater must meet the higher standard of Advanced Wastewater Treatment by 2018 and achieve at least 60% reuse of the wastewater by 2025. New or expanded ocean outfalls will not be allowed and use of the pipes will be prohibited after 2025. The six ocean outfall pipes in Palm Beach, Miami-Dade and Broward County discharge over 300 million gallons of sewer near the coral reefs of Southeast Florida.

*Wastewater and sewerage*:

- While there is a mandate to put in sewers, progress in Monroe County is running behind the mandate. The State of Florida requires Monroe County to comply with requirements to provide centralized sewer facilities throughout the Florida Keys by July 1, 2010. The Sanitary Wastewater Management Plan was approved by the Board of County Commissioners in June 2000.
- In November 2007, implementation of the Keys Wastewater Plan was estimated to cost $939 million to complete. Approximately $264 million would have been spent by the end of September 2008 to retrofit Monroe County with 2010 compliant wastewater treatment. Approximately $50 million of this cost was funded through grants from the State of Florida. The remaining cost to implement the Keys Wastewater Plan was estimated at $675 million. The funding gap between project costs and available funding was $336 million.
- Sewerage progress: Key West is fully sewered (problem here is wastewater runoff); Key Colony Beach has been for 25 years; Layton recently; North Key Largo is getting close but the problem is the unincorporated areas, 70% of which was said not to be sewered.

*Individual solutions to water shortage*:

- Water supply is again seen as the limiting factor for growth and development. Suggestions included: Composting toilets using no water and provide compost, using grey water for irrigation, and rainwater tanks.

*Other government management issues*:

- Is particular mandated government spending becoming irrelevant with climate change and sea-level rise?
- Allocation system for new residential developments determined by 24-hour hurricane evacuation time rather than environmental issues.
- Inequities in application of stormwater runoff rules.
- Lack of federal funding for authorized projects.
- Support, or lack, of sustainable building standards such as use of solar energy.
- Lack of government incentives to use appropriate technologies.
- Dependence on wastewater treatment in Miami-Dade, and on own investment in Monroe County.

### 4.2.7 ECONOMY, TOURISM, AND DIVERSIFICATION POTENTIAL

*Economy*

One of the main themes in the workshops was population change. Abstracting from the temporary respite due to the recession, it is becoming less affordable to live in the Keys with rising property values. They cause many locals to sell out at high prices, especially for waterfront property. People moving in are either buying for investment to resell, or are very wealthy buying their third or fourth homes, including Europeans.

One effect is loss of people who want to improve the community, being replaced with people who have no emotional investment. Young people are leaving. It is important to attract people who are concerned about the Keys community and environment, people who can live and work here full-time. The preservation of lifestyle is associated ultimately with the reef. Polarized wealth distribution is a big threat.

The economy has gone "full-time". One workshop participant said: "25 years ago we had a part-time economy. From Labor Day until almost Christmas you could just about sleep on US 1 without fear of getting run over. We now have a full-time economy with a geometric rise in bed taxes." *This observation is not borne out by statistical data, as shown in Chapter 6.*

Energy efficiency: Carrying capacity – does sustainable growth equal redevelopment while protecting our natural areas and achieving efficiency of energy and water use? Energy crisis and potential of alternative energy. Importance of people living with alternative energy in No Name Key.

Role of Rate of Growth Ordinance (ROGO) – limited building permits and building heights, and land use plan.

In the Lower Keys, another linchpin apart from tourism is the military economy. "Something that would really rock the foundation of this community would be a pullout of the military. It would create opportunities. But it would be a significant challenge for this economy and for the culture of this place."

*Tourism*

Tourism is the economic engine. There is a transition to an upscale economy but lack of upscale services and facilities. First-class restaurants are scarce. The need remains to import people by bus from the mainland to do the sort of mundane jobs people down here aren't taking.

The Florida Keys are a getaway destination for “millions” from Miami. Rising fuel prices will deter long-distance travel (both road and air). Refer Chapter 6 for some basic statistics.

Key West is special – historic buildings and culture, which attracts a large and diverse part of total tourism. There appears to be a source of disunity in the Keys associated with the perceived “historical” role Key West assigns to itself, which causes it to set itself apart from other Keys communities. Chapter 6 shows that its growing role is demonstrated by the most recent NOAA visitor survey showing a decline in sea-based tourist activities relative to land-based activities.

Key West is a destination for cruise ships. People in the wintertime also come down from the north through the intra-coastal waterways and spend the winter in the Keys, though mostly they go through the Bahamas.

These notes are supplemented by statistics shown in Chapter 6. The socioeconomic implications, however, cannot be entirely captured by numerical data but rely also on the strengths and weaknesses of the information extracted from the workshops.

*Diversification potential*

Like the resilience planning for the physical environment, socioeconomic resilience planning also has its place.

One topic canvassed in the workshops was what industries might be suitable for the Florida Keys if tourism declined. While referring to Appendix 2 for detailed comments, this is a selection of the suggestions:

*General*: We need to do scenario planning in a structured environment: Where do we want our community to be? What do we want our economy to look like? Something that's stable year-round. We want people to be able to live and work here and prosper here 12 months.

Diversification is compatible with addressing climate change. Primary concerns are economic diversity, infrastructure, and lifestyle (which is closely related to the reef). It is important that the character of the community is retained, and to attract those who are concerned about our community and environment rather than Costa del Sol or the Azores.

*Environmentally related educational activities*: Marriage between marine environment and marine science programs in universities. We are a living laboratory for climate change.

*Renewable energy*:

- Without a renewable energy policy the Keys' economic engine will stop if we continue to depend on drive-down traffic, cruise ships, resorts and vacations with people that have disposable income.

- Florida Power & Light is the largest producer of wind power and it's in Arizona. The Keys don't have the constant wind required.
- Tidal power: We do have constant tides and waves. Some people here are investing in a revolutionary approach to harness the power of the ocean. But we need a political mind-set and an agenda that is driven by looking at those alternatives as opposed to the current oil regime.
- Solar energy has huge potential: new solar technologies, plus longer-lived units being developed. Very little solar power has been installed in the Keys to date compared with that potential. *Note: This refers to local installation only, rather than producing panels.*
- Biodiesel from algae. A prominent scientist participating in the workshops said, "Of all the different terrestrial sources of good oil-producing plants that can produce oil for biodiesel, algae trump them by a thousand percent."

### 4.2.8 ROLE OF EDUCATION AND OUTREACH

The workshops made a great number of suggestions hard to classify but in their totality illustrating the scope of possibilities (for detail see Appendix 2):

- Education – communication – enforcement, all three are essential. There is a lack of law enforcement. Boat license conditions should be strengthened, and there should be more efficient promotion of no-take areas. Educate locals in sustainable behavior in community's interest. Educate locals as well as visiting boaters on limiting reef damage.
- Encourage environmentally aware tourist attractions; establish an ecotourism education center backed by educational institutions. Involve people already here (dive industry, FKNMS). Programs like *Green Lodging*: involve guests as part of solution – good for business too.
- There are problems educating people from diverse cultures, especially older people. Reach the parents through the children. Educate people on the success of things.
- Promote alternative energy for local use: biodiesel for boats, solar panels, tie to global change. Promote recycling campaigns. Support people leading by example such as GLEE.
- Anticipate impact of climate change (warming, sea level) to help support resilience. Adopt a long-term planning view. Learn from past mistakes.

## 4.3 INTEGRATED COASTAL AND MARINE MANAGEMENT

### 4.3.1 SANCTUARY CHARACTERISTICS

It is not the role of this project to provide detailed descriptions of existing institutions, but rather to raise issues relevant to the overall subject of *Climate Change and the Florida Keys*. The following three paragraphs summarize the character of the Sanctuary from the management plan (FKNMS 2007, *About this document*):

"The Florida Keys National Marine Sanctuary extends approximately 220 nautical miles southwest from the southern tip of the Florida peninsula. The Sanctuary's marine ecosystem supports over 6,000 species of plants, fishes, and invertebrates, including the nation's only living coral reef that lies adjacent to the continent. The area includes one of the largest seagrass communities in this hemisphere. Attracted by this tropical diversity, tourists spend more than thirteen million visitor days in the Florida Keys each year. In addition, the region's natural and man-made resources provide livelihoods for approximately [73,000] residents.

The Sanctuary is 2,900 square nautical miles of coastal waters, including the recent addition of the Tortugas Ecological Reserve. The Sanctuary overlaps six State parks and three State aquatic preserves. Three national parks have separate jurisdictions, and share a boundary with the Sanctuary. In addition, the region has some of the most significant maritime heritage and historical resources of any coastal community in the nation.

The Sanctuary faces specific threats, including direct human impacts such as ship groundings, pollution, and overfishing. Threats to the Sanctuary also include indirect human impacts, which are harder to identify but seem to be reflected in coral declines and increases in macroalgae and turbidity. More information about the Sanctuary can be found in this document and at the Sanctuary's web site: http://floridakeys.noaa.gov."

It is striking that the perceived threats when the management plan was developed were associated with direct human impacts rather than the impact of climate change. This has definitely changed, as evidenced by a presentation in August 2009 on ocean acidification by the Regional Director for NOAA's National Marine Sanctuary Program to the bimonthly Florida Keys National Marine Sanctuary Advisory Council (SAC) meeting (Causey 2009).

### 4.3.2 Sanctuary Management Style

"Integrated management" is the best way to describe how the Florida Keys National Marine Sanctuary works with local, state and other federal agencies to foster compatible management strategies and policies, based on multiple jurisdictions. The FKNMS itself is one of 13 marine protected areas managed by NOAA's National Ocean Service (NOS), ranging from the Pacific (Hawaii and American Samoa) to the Florida Keys and three other areas along the Atlantic coast of the United States.

The description here focuses naturally on the FKNMS and its efforts to value and preserve the marine ecosystem and improve its resilience in a manner that takes all the ecological, socioeconomic and demographic interdependencies into account. The next section (4.4) highlights the role of volunteer groups and non-government organizations in the area.

The key issue facing sanctuary management in conditions of threatening climate change was discussed in Section 4.2.5: enhancing coral reef resilience in the effort to improve reef health. This matter will become increasingly urgent as climate change gathers pace and affects sea surface temperatures, sea levels, and ocean chemistry.

The strong impression formed during this project is that an *adequately funded* FKNMS is excellently equipped, institutionally and through the expertise of its management and staff, to deal with climate change as long as the change remains *manageable*. Note the two provisos: adequate funding and climate change remaining controllable. Funding sources are complex and no trends have been identified – however the case remains that the aggravated circumstances as climate change accelerates will put further pressures on the FKNMS.

This author claims no specific expertise in sanctuary management, but offers his views as an observer. The integrated management style across all three levels of government, and the consultative role of the Sanctuary Advisory Council and the mature manner in which information and advice is exchanged between the FKMNS management team and SAC is impressive. The quality of leadership and information exchange can only be applauded.

Funding does have to be an issue, however. Clearly, the increasing danger signals from climate change and the gaps that remain in knowledge at all levels are challenges that must be met. This will require increased budgets.

Integrated management itself is also an issue because the reef ecosystem is managed by different government agencies with specific spatial jurisdictions. Fisheries are managed by the Florida Fish and Wildlife Conservation Commission and two federal fishery management councils (US South Atlantic and Gulf of Mexico). Different fishing regulations can also apply in the Florida Keys National Marine Sanctuary (FKNMS), in three national parks (Biscayne, Everglades, Dry Tortugas) and four National Fish and Wildlife Refuges (Department of Interior); and in the John Pennekamp Coral Reef State Park managed by the Florida Department of Environmental Protection (Ault et al. 2005, p 600).

Finally, Florida Bay is 85% part of the Everglades National Park with the remainder mainly under FKNMS. The health of the Bay is vital for the rest of the Florida Keys, as discussed elsewhere.

### 4.3.3 The Sanctuary Advisory Council – role in integrated management

The SAC was established by the US Secretary of Commerce in 1992 to provide advice to the Sanctuary superintendent and the Director of the Office of Coastal and Aquatic Managed Areas of the Florida Department of Environmental Protection. SAC members are appointed by NOAA, in consultation with the State of Florida. Members include representatives of nominated commercial and recreational user groups (commercial and recreational fishermen, the dive industry, and the boating industry), conservation and other public interest organizations, scientific and educational organizations, and members of the public interested in the protection and multiple-use management of Sanctuary resources. (The website, http://floridakeys.noaa.gov/sac/welcome.html, shows the current membership and the minutes of all bimonthly meetings held since the beginning of 2000 – well worth visiting for current issues and a historical perspective.)

The issues were taken up by Daniel O. Suman of the University of Miami relatively early in the life of the FKNMS (Suman 1997). He noted that SAC was "a new experiment in 'citizen governance' of the Sanctuary" (p 296). All the signs are that constructive cooperation between SAC and FKNMS management has continued into 2010.

SAC is reported to have played an important role in the planning process since its formation in February 1992. It played a significant and strong role in the development of the first final FKNMS management plan, dated September 1996. In the process, it elevated some issues, such as Florida Bay restoration, that had not been targeted by the Inter-Agency Core Group which was formed in 1991 representing three State departments and the Florida Governor's office. Representing most of the marine resource user groups, the SAC was able to develop an acceptable and feasible plan for the debated sanctuary zones (Suman 1997, p 297)

Integrated management also characterizes the cooperation between state and federal authorities. After the Congressional designation of the FKNMS in 1990, a close partnership between the federal government and the State of Florida has characterized sanctuary planning and development of the management plan.

### 4.3.4 A vote on resilience strategies

The FRRP conference in April 2008 described in Section 4.2.5 surveyed a large number of potential resilience strategies to find the most popular or acceptable ones. Figure 4.2 shows the top 10 preferences according to the conference participants. Four of the ten preferences were of a regulatory nature (shown in blue), three research and monitoring (brown), two voluntary “best use practices” (pink), and only one education and outreach (orange). This result are at least indicative evidence of reef managers’ thinking. The ten strategies received between 49 and 37 votes from the conference participants, while another 15 received between 21 and 35, and 33 between 10 and 19 – leaving the remaining 100 potential resilience strategies with single-digit votes at the conference (refer FRRP 2008).

### 4.3.5 Marine zoning

| | |
|---|---|
| 1 | Devise a comprehensive plan for marine zoning based on reef resilience principles, best available biophysical and social science and reef user input. Account for environmental protection and sustainability of commercial and recreational uses. (Reg) |
| 2 | Create a boating license similar to a driver's license (Reg) |
| 3 | Encourage dive tour operators and other groups and users to get involved in monitoring. BleachWatch, MEERA etc (possibly model on Great Barrier Reef's "Eyes on the Reef" program) and integrate these into a centralized, user-friendly reporting system (R&M) |
| 4 | Keep lobster and crab traps away from living corals (Vol) |
| 5 | Continue examining relationships between local environmental conditions (e.g. UV/light, water quality, currents, doldrums, and other contaminants, etc.), biological and physical environment and bleaching to better understand reef resilience to climate change. Expand existing efforts focused on the Keys to the mainland (R&M) |
| 6 | Blue Star: Dive and snorkel operators get certified, divers and snorkelers use certified operators. Includes environmental and climate change briefing and general green practices (Vol.) |
| 7 | Increase law enforcement presence in general and focus effort on resilient reef areas (Reg) |
| 8 | Policy makers. They have the power (Edu) |
| 9 | Regularly communicate analytic results to reef managers and the public to best address their needs (R&M) |
| 10 | User fee for all reef users (Reg) |

Potential strategies represented: Regulatory (1,2,7,10). Research and monitoring (3, 5, 9). Voluntary "best reef use practices" (4, 6). Education, outreach, awareness and appreciation (8). Source: FRRP (2008)

***Figure 4.2: Top 10 votes among 158 potential resilience strategies for Florida Keys, April 2008***

There are currently five current zoning types in the FKNMS area: Sanctuary Preservation Areas (SPAs), Ecological Reserves (ERs), Special Use Areas, Research Only Areas, and Wildlife Management Areas. Approximately 6% of the total FKNMS area, mainly in the Dry Tortugas, is closed to all extractive uses, or “take” – this is insufficient according to a special Sanctuary Advisory Council workshop which reported in March 2008 (FKNMS-SAC 2008). The workshop advocated new and larger SPAs, and no-take buffers around existing SPAs and/or more ERs.

The circumstances may be different, but the low proportion of Marine Protected Areas (MPAs), especially in the Florida Keys area itself, contrasts with actions taken to protect the Great Barrier Reef, where the Australian Government increased the protected area from 4.6% to 33.3% in 2004, making the Great Barrier Reef Marine Park the largest protected sea area in the world. The recommendations of the SAC workshop were debated by the bimonthly SAC meeting on July 11, 2008, although no firm decisions were taken.

Climate change will have increasing, mutually reinforcing, impacts on ocean warming, ocean acidification, sea-level rise, the variations in ocean-atmosphere interactions and ocean circulation (including the El Niño-Southern Oscillation and Pacific Decadal Oscillation), increasing storm intensity, and worldwide changes in the amount, intensity, frequency and type of precipitation which will increase the salinity in the shallower parts of the tropical and subtropical oceans (Keller et al. 2009).

Climate change, these authors continue, interacts with "traditional" stressors of coral reefs and other ecosystems: land-based pollution sources, overfishing and destructive fishing practices, non-indigenous and invading species, and disease. They conclude that options for MPA management must be taken to ameliorate existing "traditional" stressors, to protect potentially resilient areas, and to develop MPA networks.

The section of the paper dealing with MPA networks says it all: "For both terrestrial and marine systems, species diversity often increases with habitat diversity, and species richness increases with habitat complexity; the greater the variety of habitats protected, the greater the biodiversity conserved. High species diversity may increase ecosystem resilience by ensuring sufficient redundancy to maintain ecological processes and protect against environmental disturbance for both terrestrial and marine systems. This is particularly the case in the context of additive or synergistic stressors. Maximizing habitat heterogeneity is critical for maintaining ecological health, thus MPAs should include large areas and depth gradients. By protecting a representative range of habitat types and communities, MPAs have a higher potential to protect a region's biodiversity, biological connections between habitats, and ecological functions." (Keller et al. 2009, "Develop MPA networks")

Significantly, a comprehensive marine zoning plan based on resilience principles was the top strategy voted by the participants in the 2008 FFRP conference (Figure 4.2).

## 4.4 COMMUNITY ORGANIZATIONS

Local community organizations are important in the Keys area. Among the most prominent are Green Living & Energy Education (GLEE) and SFFFK (Sanctuary Friends Foundation of the Florida Keys). Since its creation in 2003, GLEE has been a powerful catalyst for climate change mitigation at the local level (Bergh 2009). Other local organizations include Last Stand, organized to promote, preserve, and protect the quality of life in the city of Key West, the Florida Keys and their environs, with particular emphasis on the natural environment. The Key Deer Protection Alliance and FAVOR (Friends and Volunteers of Refuges) have special missions protecting endangered species in the Florida Keys.

Reef Relief, founded in 1987 in Key West, has a long history of preserving and protecting living coral ecosystems, including installation of mooring buoys, creating coral nurseries, and conducting ongoing surveys of coral health leading to the discovery of several new coral diseases. The organization now operates in many other areas apart from the FKNMS area.

Other organizations of local importance and beyond includes Chambers of Commerce in Key Largo, Islamorada, Marathon, Lower Keys, and Key West. While primarily serving commercial interests, these are influenced by an environmentally sensitive tourism industry. GLEE in 2009 launched a Certified Green Business program, based on a pilot process in which the Lower Keys Chamber of Commerce and Visitor Center became one of only two member operations to qualify (http://www.keysglee.com/index.cfm/green-business-directory/ shows the number rising to nine by July 11, 2010). The GLEE initiative provides "an easy to follow, step-by-step, DIY greening process. Once the required measures have been implemented, an on-site assessment is conducted. If all standards are met, the business becomes certified, a recognition that includes several rewards and incentives designed to inspire businesses to get with the program."

Some local organizations have broader geographical links. Beyond the Florida Keys, the Florida Climate Alliance fosters State leadership in mitigating and adapting to the challenge of global warming. The FCA is itself part of the Southeast Coastal Climate Network, which consists of coastal organizations working towards climate solutions from Louisiana to Maryland.

Internationally, NGOs focused on climate change mitigation include the international ICLEI – Local Governments for Sustainability, founded in 1990. Its growing membership includes over one thousand cities, towns, countries and their associations.

Of the worldwide non-government organizations that are active in the Florida Keys, TNC (The Nature Conservancy) has already been mentioned. It has had a presence in the area going back at least to the 1990s. WWF has also traditionally been an important presence.

Audubon of Florida operates the Tavernier Science Center in the Upper Keys, concentrating on estuarine and marine research. TSC scientists are currently studying the flow of freshwater into Florida Bay and the impacts the diversion of water has had throughout the Everglades ecosystem.

The non-government and volunteer organizations, as well as working on similar causes or in association with the FKNMS and others, are finding increased opportunities for cooperation as government authorities at all levels develop new approaches to dealing with environmental issues. Climate change mitigation is being addressed by institutions from international to municipal level. "Non-regulatory bodies like the IPCC, the US Mayors Climate Protection Task Force, the Florida Energy and Climate Commission, Monroe County's Green Initiatives Task Force and local government "green teams" for the City of Key West, City of Marathon, City of Key Colony Beach, City of Layton, [and] Islamorada, Village of Islands, play an increasing role in developing and tracking mitigation actions." (Bergh 2009)

# 5 BIOPHYSICAL RESEARCH

## 5.1 OVERVIEW

Previous chapters have commented on a range of physical research matters including sea-level rise and marine sanctuary management which are subjects of intensive environmental research undertaken over a long period, focusing on reef health. We now focus on coral cover and trends in commercial fishery landings. Section 5.3 shows statistics, while Section 5.4 notes some of the ongoing work on marine life biology and ecology around the Florida Keys.

## 5.2 CORAL COVER AND HEALTH

Coral cover is the proxy for coral reef condition according to Woesik (2008), whose presentation at the FRRP conference included a chart showing coral cover in the Caribbean falling from over 50% in 1977 to less than 10% in 2000. The situation may have deteriorated even more dramatically (Richardson and Voss 2005): While widespread occurrences of total coral colony mortality, partial mortality, population decline, and apparent decreases in coral recruitment have been reported on many reefs, these problems are particularly prominent in the wider Caribbean where it has been estimated that coral cover has declined by 80% over the past 30 years.

Anecdotal evidence (including older participants recalling the 1950s and 1960s at the 2008 scenario-planning workshops reported in Appendix 2) suggests that large reductions of coral cover have also taken place in the Florida Keys.

**Table 5.1: Coral cover in the Florida Keys and Dry Tortugas**

| | Lower Keys | Middle Keys | Upper Keys | Total FKNMS | Dry Tortugas |
|---|---|---|---|---|---|
| Stations → | 46 | 27 | 28 | 101 | 12 |
| 1996 | 15.3% | 7.3% | 12.4% | 12.3% | |
| 1997 | 14.7% | 7.2% | 11.4% | 11.8% | |
| 1998 | 12.6% | 6.3% | 9.1% | 10.0% | |
| 1999 | 9.3% | 5.3% | 7.3% | 7.7% | 18.9% |
| 2000 | 9.6% | 5.4% | 7.1% | 7.8% | 17.4% |
| 2001 | 9.3% | 5.5% | 7.1% | 7.7% | 17.4% |
| 2002 | 8.9% | 5.9% | 7.2% | 7.6% | 14.1% |
| 2003 | 8.7% | 5.5% | 7.2% | 7.4% | 13.4% |
| 2004 | 7.9% | 5.0% | 6.9% | 6.9% | 11.7% |
| 2005 | 8.0% | 5.6% | 6.6% | 7.0% | 11.4% |
| 2006 | 7.2% | 5.0% | 5.9% | 6.3% | 8.8% |
| 2007 | 7.0% | 5.1% | 7.0% | 6.5% | 9.8% |
| 2008 | 6.8% | 5.1% | 6.9% | 6.4% | 10.3% |

Source: Coral Reef Evaluation and Monitoring Project (CREMP): From worksheet CREMP_FKNMS_PCgrp_9608_101stn

**Table 5.2: Stony coral cover, Florida Keys, by habitat**

| | Hardbottom | Offshore deep | Offshore shallow | Patch |
|---|---|---|---|---|
| **Lower Keys** | | | | |
| 1996 | 1.2% | 7.6% | 16.9% | 24.8% |
| 1997 | 1.1% | 7.9% | 16.4% | 22.9% |
| 1998 | 1.4% | 5.3% | 13.2% | 22.4% |
| 1999 | 1.4% | 4.2% | 7.3% | 19.2% |
| 2000 | 1.2% | 4.3% | 7.4% | 20.1% |
| 2001 | 2.3% | 4.4% | 6.9% | 19.0% |
| 2002 | 0.5% | 4.2% | 7.4% | 17.6% |
| 2003 | 0.6% | 3.9% | 7.3% | 17.5% |
| 2004 | 0.4% | 3.1% | 7.0% | 16.0% |
| 2005 | 0.6% | 3.2% | 5.5% | 17.9% |
| 2006 | 0.3% | 1.9% | 4.9% | 17.2% |
| 2007 | 0.4% | 2.3% | 4.9% | 16.3% |
| 2008 | 0.2% | 2.4% | 4.7% | 15.7% |
| **Middle Keys** | | | | |
| 1996 | 3.8% | 4.1% | 4.6% | 15.8% |
| 1997 | 3.8% | 4.8% | 4.2% | 15.6% |
| 1998 | 2.9% | 3.4% | 3.7% | 14.4% |
| 1999 | 3.2% | 3.0% | 2.0% | 13.2% |
| 2000 | 2.6% | 2.8% | 2.0% | 14.2% |
| 2001 | 2.9% | 3.0% | 1.9% | 14.1% |
| 2002 | 2.3% | 2.7% | 2.1% | 16.3% |
| 2003 | 2.7% | 2.9% | 1.8% | 14.7% |
| 2004 | 1.9% | 2.5% | 1.7% | 13.6% |
| 2005 | 2.5% | 2.7% | 1.8% | 15.1% |
| 2006 | 1.9% | 2.3% | 1.4% | 14.2% |
| 2007 | 1.8% | 2.0% | 1.2% | 15.3% |
| 2008 | 1.8% | 2.2% | 1.7% | 14.3% |
| **Upper Keys** | | | | |
| 1996 | | 7.4% | 12.1% | 16.3% |
| 1997 | | 6.1% | 11.2% | 15.2% |
| 1998 | | 3.5% | 8.3% | 14.0% |
| 1999 | | 3.4% | 5.9% | 11.9% |
| 2000 | | 3.6% | 5.9% | 11.3% |
| 2001 | | 2.9% | 5.6% | 12.2% |
| 2002 | | 3.0% | 5.6% | 12.2% |
| 2003 | | 3.1% | 5.2% | 12.6% |
| 2004 | | 2.7% | 4.9% | 12.5% |
| 2005 | | 2.7% | 4.8% | 11.8% |
| 2006 | | 2.3% | 4.1% | 11.0% |
| 2007 | | 3.2% | 4.5% | 13.2% |
| 2008 | | 3.0% | 4.8% | 12.7% |

Source: CREMP worksheets

Comprehensive hard evidence based on constant surveying, however, is only available since 1996, through the Coral Reef Evaluation and Monitoring Project (CREMP) which is part of the FKNMS Water Quality Protection Program and is administered by the Florida Fish and Wildlife Research Institute (FWRI). The mean stony coral cover fell from 12.3% in 1996 to 6.4% in 2008, though it seems to have stabilized over the last three years (Table 5.1). The same applies to each section of the Keys (Lower, Middle, Upper), and the Dry Tortugas. The deterioration was worst in the Lower Keys and least pronounced in the Middle Keys, which even in 1996 was only 7.3%, from which it has fallen further to 5.1%.

Besides monitoring coral cover, CREMP has noted a slight upward trend in the number of stations with the herbivorous sea urchin *Diadema antillarum* (see Section 4.2.5), though the percentage of stations remains modest at around 10%. There is a slightly more positive development in the incidence of coral disease, another object of CREMP monitoring. The incidence of black band disease peaked in 1998, and white disease (white plague, white band and white pox) and other diseases including dark spot, yellow band and idiopathic diseases have been generally declining. However, the incidence of white disease increased significantly between 2005 and 2006, to more than half the stations.

The 1983-84 Caribbean-wide mortality of *Diadema antillarum* was followed by a second mortality event in the Florida Keys in 1991. The demise of this once ubiquitous herbivore is recognized as a factor contributing to wider Caribbean reef change during the past 25 years. A survey of 786 sites from the northern extent of the Florida Reef Tract to the Dry Tortugas, including two National Parks and the FKNMS, found that while pre-1983 densities were as high as five individuals per $m^2$, surveys since 1999 at a range of depths show that densities are still well below one individual per $m^2$ (Chiappone et al. 2008).

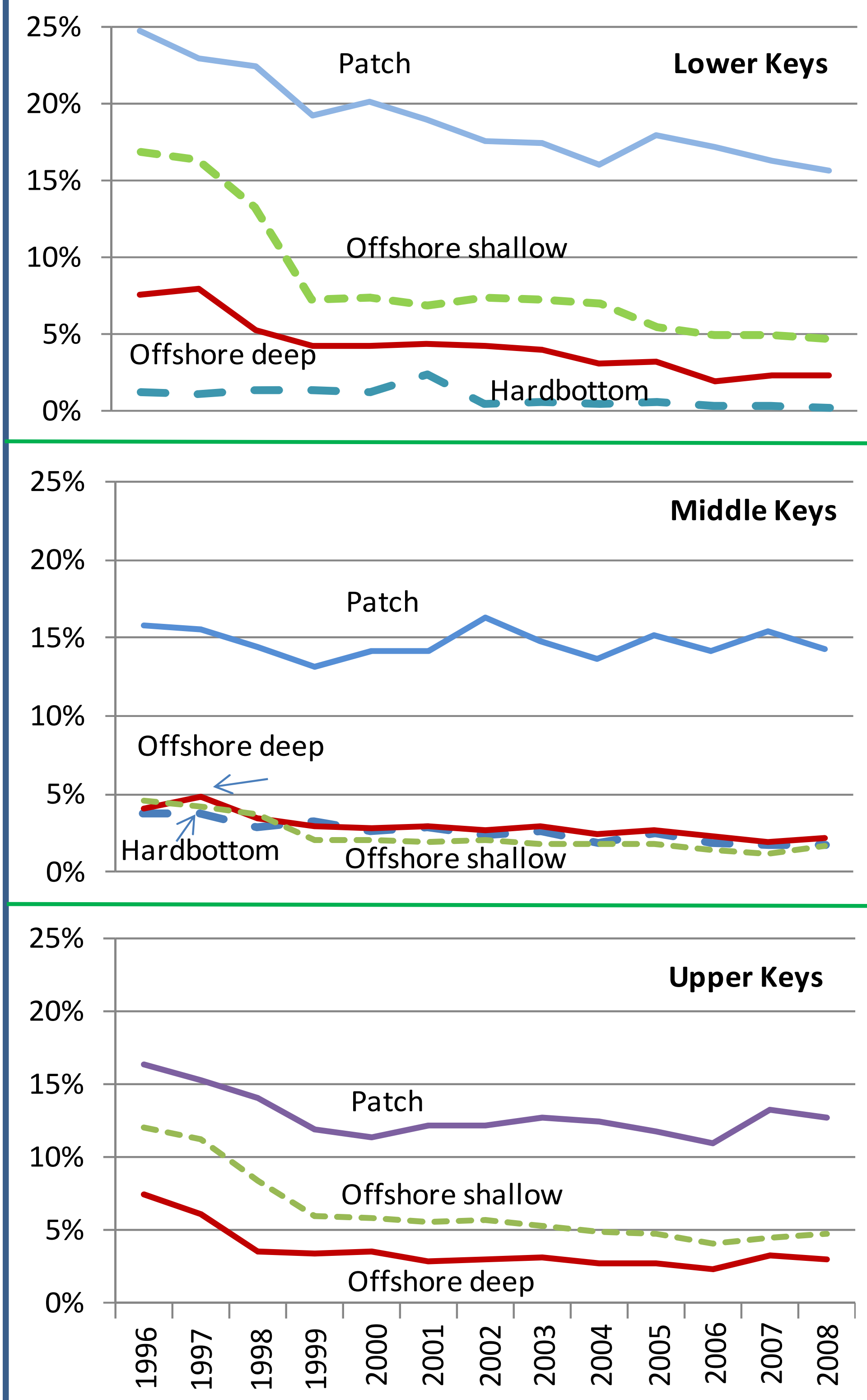
Coral cover is highest on patch reefs, in the Upper, Middle, and Lower Keys. Between 1996 and 2008, patch reef cover declined most strongly in the Lower Keys, but remained slightly higher than in the two other regions (Table 5.2 and Figure 5.1). The Lower Keys also lost the most cover from deep and shallow offshore reefs and in hardbottom areas, which cover some 40% if the seafloor in the shallow waters of the marine ecosystem.

The Dry Tortugas has also lost coral cover despite its isolation from coastal development (Table 5.3). Patch reef cover is much less than in the Florida Keys, while the cover remains significantly higher in offshore deep areas. These observations were taken directly from the CREMP source shown below Table 5.1.

Other techniques have been used to measure the change in coral cover, including the use of satellite data. Landsat images from 1984 to 2002 were adapted to measure habitat changes for eight coral reefs in the FKNMS (Palandro et al. 2008). While the results differed from reef to reef, the coral habitat decline for all the reef sites was 61% over 18 years (an average annual loss of 3.4%). CREMP observations for the same reefs were correlated with these results and no statistically significant difference found.

Another important research effort in the Florida Keys into coral health and cover is headed by Steven Miller, an ecologist with the University of North Carolina-Wilmington working in Key Largo, and his colleague Mark Chiappone. Miller and Chiappone have taken a different approach from the CREMP team, with a program which is apparently the only one that takes a specific look at conditions inside and outside protected areas. The approach is based on randomly stratified benthic sampling to make it representative of the reef geography of the Keys. Since it began in 1999 it has brought many new insights to bear.

**Figure 5.1: Stony coral cover, Florida Keys, by habitat**




Source: CREMP

The declines in abundance of two of the principal Caribbean reef-building corals, Staghorn coral (*Acropora cervicornis*) and Elkhorn coral (*A. palmata*), are often-cited examples of the changes in western Atlantic reefs that have occurred during the past several decades. The causes of these declines, which began in the late 1970s, include large-scale factors such as coral bleaching and disease, especially white band disease which was in evidence long before other misfortunes hit, such as the near-eradication of *Diadema antillarum* in 1983-84 and the first major bleaching events in the Florida Keys.

**Table 5.3: Stony coral cover, Dry Tortugas**

| | Offshore deep | Patch |
|---|---|---|
| 1999 | 23.6% | 9.5% |
| 2000 | 22.1% | 8.0% |
| 2001 | 23.3% | 5.8% |
| 2002 | 18.3% | 5.6% |
| 2003 | 18.0% | 4.2% |
| 2004 | 16.6% | 1.9% |
| 2005 | 16.3% | 1.6% |
| 2006 | 12.6% | 1.1% |
| 2007 | 14.0% | 1.2% |
| 2008 | 14.5% | 1.8% |

Source: CREMP

Two whole-reef investigations at the Looe Key National Marine Sanctuary in 1983 and 2000 showed a 93% decline in the total area of live *A. palmata*, and a 98% decline for *A. cervicornis* (Margaret Miller et al. 2002). The decline would have been even worse but for a loss of only 25% for *A. palmata* in one of the six sections of the reef, while losses exceeded 97% in the five other sections. Similarly, for *A. cervicornis*, one section showed a decline of 51%, and all the other sections declines of 99-100%. In contrast to the Indo-Pacific, which is host to a plethora of acroporid corals, *A. palmata* and *A. cervicornis* have been the major reef-building coral species for most of the past 500,000 years throughout the Caribbean, serving another important ecological function of coral reefs by providing habitat for numerous reef fish species.

While the 2002 paper quoted above suggested that the dramatic loss at Looe Key Reef was representative of the Florida Keys, an intensive survey undertaken more recently by Steven Miller and colleagues (Miller et al. 2008) seems to tell a slightly more optimistic story of *Acropora* corals in the Florida Keys. The authors quantified habitat distribution, colony abundance, size, and condition at 235 sites spanning over 200 km. *A. cervicornis* was widely distributed among sites and habitats and was particularly abundant on patch reefs. *A. palmata* was abundant on shallow spur and groove reefs. Although the prevalence of disease is relatively low, both species continue to suffer predation, as well as physical impacts from lost fishing gear. Predicting the future of these corals in Florida requires information about both their present-day ecology and geologic history in Florida.

Bringing the geology into the picture is the theme of Precht and Miller (2007) who note that the ecology of Caribbean and western Atlantic coral reefs has changed dramatically in recent decades especially along the Florida reef tract.

"Whether these recent changes are natural cyclic events or the result of human activities has been a topic of strenuous debate. To address this issue, we asked the question, "Did episodes of reef degradation occur in the past, before the era of human interference, or is the current state of coral reefs unique to our time?"business-as-usual" (pp 237-238)

"Because coral reefs are both geologic and biologic entities, it is possible to observe the effects of various disturbances in ecological time, detect historical changes in the paleoecological record, and deduce the multiscale processes behind those patterns. For Florida at least, the present reef community assemblage, highlighted by diminishing *Acropora* populations, is not unique in space or in time." (p 284)

The authors conclude that quaternary reefs in Florida emphasize the resilience of reef ecosystems and the responses of coral species to rapid environmental change in the absence of major human modification of the seascape. These ecological shifts in coral community composition allow us to use the past as a key to predicting the future of reefs in a world now besieged by numerous disturbances from natural and human influences.

**Table 5.4: Annual commercial fishery landings, Monroe County**

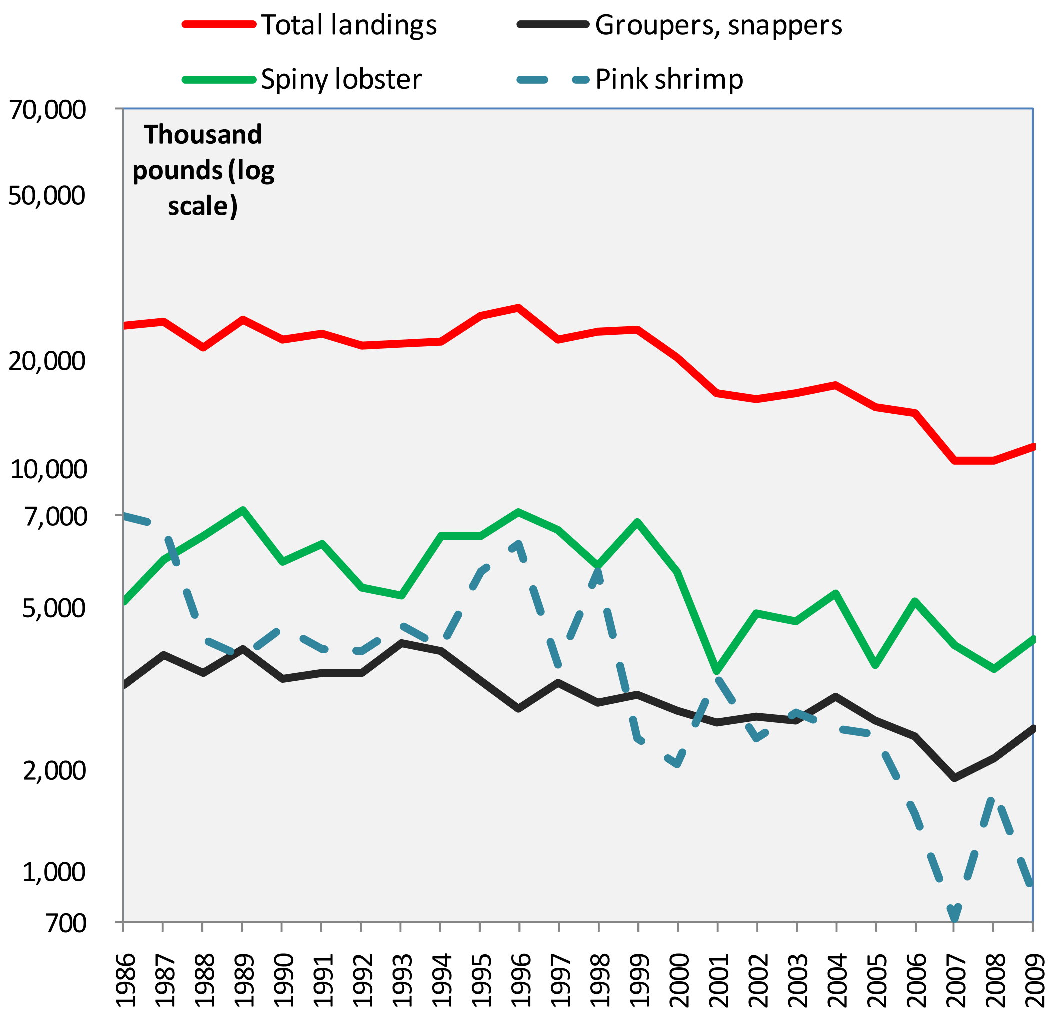
| Thousand Pounds | Groupers, snappers | Other finfish | Total finfish | Spiny lobsters | Pink shrimp | Other in-vertebrates | Total landings |
|---|---|---|---|---|---|---|---|
| 1986 | 2,679 | 5,636 | 8,315 | 4,333 | 7,027 | 936 | 20,612 |
| 1987 | 3,177 | 4,749 | 7,926 | 5,467 | 6,601 | 1,010 | 21,005 |
| 1988 | 2,896 | 4,386 | 7,281 | 6,263 | 3,471 | 1,220 | 18,235 |
| 1989 | 3,293 | 5,824 | 9,116 | 7,255 | 3,162 | 1,619 | 21,153 |
| 1990 | 2,796 | 5,168 | 7,964 | 5,434 | 3,725 | 1,812 | 18,935 |
| 1991 | 2,885 | 5,696 | 8,581 | 5,999 | 3,285 | 1,902 | 19,767 |
| 1992 | 2,873 | 5,435 | 8,307 | 4,665 | 3,269 | 2,049 | 18,291 |
| 1993 | 3,403 | 5,218 | 8,621 | 4,448 | 3,764 | 1,847 | 18,679 |
| 1994 | 3,273 | 3,938 | 7,211 | 6,239 | 3,323 | 1,943 | 18,716 |
| 1995 | 2,754 | 5,226 | 7,980 | 6,245 | 5,090 | 2,546 | 21,861 |
| 1996 | 2,356 | 4,934 | 7,291 | 7,139 | 5,969 | 2,251 | 22,649 |
| 1997 | 2,727 | 3,824 | 6,551 | 6,461 | 3,023 | 2,908 | 18,943 |
| 1998 | 2,421 | 3,773 | 6,194 | 5,268 | 5,088 | 3,290 | 19,841 |
| 1999 | 2,546 | 3,969 | 6,515 | 6,794 | 1,995 | 4,804 | 20,108 |
| 2000 | 2,328 | 3,539 | 5,866 | 5,115 | 1,716 | 4,409 | 17,106 |
| 2001 | 2,167 | 3,659 | 5,826 | 2,904 | 2,833 | 2,514 | 14,076 |
| 2002 | 2,240 | 3,336 | 5,576 | 4,036 | 1,993 | 1,944 | 13,550 |
| 2003 | 2,199 | 3,809 | 6,008 | 3,851 | 2,310 | 1,926 | 14,094 |
| 2004 | 2,511 | 3,366 | 5,877 | 4,496 | 2,112 | 2,214 | 14,699 |
| 2005 | 2,200 | 4,439 | 6,638 | 3,027 | 2,038 | 1,346 | 13,050 |
| 2006 | 2,011 | 3,675 | 5,686 | 4,327 | 1,303 | 1,191 | 12,506 |
| 2007 | 1,593 | 2,564 | 4,157 | 3,379 | 719 | 1,323 | 9,579 |
| 2008 | 1,783 | 2,410 | 4,193 | 2,955 | 1,491 | 990 | 9,628 |
| 2009 | 2,111 | 3,227 | 5,338 | 3,493 | 821 | 772 | 10,424 |

Source: Fish and Wildlife Research Institute (FWRI), Florida Fish and Wildlife Conservation Commission, Marine Fisheries Information System, Edited Annual Landings Summary (2009 preliminary)

## 5.3 COMMERCIAL FISHERY LANDINGS

Annual surveys of fishery landings by species go back to 1986 and are compiled by the Florida State Fish and Wildlife Research Institute (FWRI). The statistical record covers all significant Florida species by county. Table 5.4 shows the time series for Monroe County which includes the Florida Keys. The "snapper-grouper complex" represents the main commercial *reef fish* fishery and consists of 73 species of mostly groupers and snappers, but also grunts, jacks, porgies, and hogfish (Ault et al. 2005a). Twenty-seven of these are specified in the commercial fishing regulations (FWC 2009). Invertebrate landings included spiny lobster, pink shrimp, and other invertebrates. Average commercial prices in 2009 were generally $2 to $3 for most grouper and snapper species, compared with $1.35 for total finfish. Average prices for invertebrates were $3.12 for spiny lobster, and $2.75 for all invertebrates (excluding shrimp). Shrimp prices averaged $1.55 for all food shrimp and $1.85 for the dominant pink shrimp. These data show that fishery landings in Monroe County are valuable.

**Figure 5.2: Trends in main commercial fishery landings: Monroe County**




**Source: FWRI (full description below Table 5.4)**

Total landings, however, have declined. Figure 5.2 uses a logarithmic scale to show rates of change. Total Monroe County landings stayed reasonably constant above 20 million pounds per year from 1986 to 1999, but since then dropped by half although some improvement occurred between 2007 and 2009. Total landings of groupers and snappers, and spiny lobsters, also declined. These trends, expressed as the change in the three-year moving average between 1986-88 and 2007-09, showed that groupers and snappers declined 37% (2.917 to 1.829 million pounds),spiny lobster declined 39% (5.355 to 3.276 million pounds) while total landings for Monroe County declined 50% (19.951 to 9.877 million pounds). Despite absolute declines in reef fisheries for snapper and grouper and spiny lobster, these fisheries were relatively successful compared to landings of all other finfish and invertebrate species which fell by 59%.

The situation is different, however, if we take pink shrimp into consideration (shown as a dotted line on Figure 5.2). The three-year moving average fell from 5.7 million pounds in 1986-88 to only 1.01 million pounds in 2007-09, or by 82%. The declining trend has been particularly fierce since 2005.

**Table 5.5: Total annual commercial fishery landings in Florida**

| Thousand Pounds | Groupers, snappers | Other finfish | Total finfish | Spiny lobsters | Pink shrimp | Other in-vertebrates | Total landings |
|---|---|---|---|---|---|---|---|
| 1986 | 20,587 | 101,183 | 121,770 | 5,031 | 14,037 | 32,807 | 173,644 |
| 1987 | 21,839 | 102,717 | 124,556 | 6,092 | 12,452 | 50,076 | 193,176 |
| 1988 | 18,588 | 99,819 | 118,407 | 6,803 | 9,298 | 46,883 | 181,391 |
| 1989 | 23,391 | 115,484 | 138,875 | 7,814 | 9,255 | 41,483 | 197,427 |
| 1990 | 21,701 | 106,033 | 127,734 | 6,019 | 8,422 | 36,571 | 178,746 |
| 1991 | 20,153 | 92,734 | 112,887 | 7,020 | 8,559 | 27,104 | 155,570 |
| 1992 | 19,572 | 93,619 | 113,191 | 5,333 | 8,078 | 37,963 | 164,566 |
| 1993 | 21,996 | 84,341 | 106,337 | 5,377 | 11,421 | 40,161 | 163,296 |
| 1994 | 19,408 | 78,450 | 97,858 | 7,087 | 9,721 | 46,975 | 161,641 |
| 1995 | 16,558 | 47,798 | 64,356 | 7,002 | 14,824 | 40,969 | 127,150 |
| 1996 | 14,974 | 38,853 | 53,827 | 7,866 | 19,532 | 60,637 | 141,862 |
| 1997 | 15,889 | 42,442 | 58,331 | 7,108 | 14,273 | 37,394 | 117,107 |
| 1998 | 15,133 | 41,592 | 56,725 | 5,831 | 18,548 | 43,640 | 124,744 |
| 1999 | 17,634 | 42,503 | 60,137 | 7,577 | 10,605 | 42,787 | 121,106 |
| 2000 | 17,523 | 36,006 | 53,529 | 5,764 | 9,305 | 37,451 | 106,049 |
| 2001 | 18,707 | 38,860 | 57,567 | 3,405 | 11,313 | 31,529 | 103,815 |
| 2002 | 18,172 | 37,832 | 56,005 | 4,483 | 11,697 | 25,177 | 97,362 |
| 2003 | 17,142 | 37,481 | 54,624 | 4,262 | 11,626 | 28,033 | 98,544 |
| 2004 | 17,679 | 35,934 | 53,613 | 4,976 | 12,620 | 39,295 | 110,503 |
| 2005 | 15,861 | 33,649 | 49,510 | 3,364 | 10,897 | 27,097 | 90,868 |
| 2006 | 14,103 | 36,828 | 50,931 | 4,773 | 9,992 | 31,598 | 97,294 |
| 2007 | 12,657 | 32,041 | 44,698 | 3,760 | 5,206 | 30,169 | 83,833 |
| 2008 | 14,979 | 34,282 | 49,260 | 3,479 | 7,183 | 24,231 | 84,153 |
| 2009 | 14,092 | 35,240 | 49,332 | 3,815 | 5,445 | 23,090 | 81,682 |

Source: See Table 5.4

Table 5.5 shows that the state-wide declines occurred in all five categories, but were most pronounced in finfish other than groupers and snappers which declined about two-thirds, based on three-year averages (1986-88 to 2007-09). Most of the decline, however, happened before 1996 with smaller declines thereafter. Pink shrimp landings declined by half.

Table 5.6 shows that reef fish landed in Monroe County averaged 14.3% of the total Florida reef fish landed between 1986 and 2009, slightly above the County's overall average share of 13.2%. The Monroe County had a much higher share of spiny lobster (average 89.1%).

Excluding grouper and snapper, the Monroe County share was 8.1% for finfish and 10.7% for invertebrates other than spiny lobster. This share was much lower in recent years due to the decline in pink shrimp. Monroe County averaged 28% of total Florida landings over the full 23 years in the statistics, but after the declines accounted for only 15% in 2009.

**Table 5.6: Annual commercial fishery landings, Monroe County share of Florida**

| Thousand Pounds | Groupers, snappers | Other finfish | Total finfish | Spiny lobsters | Pink shrimp | Other in-vertebrates | Total landings |
|---|---|---|---|---|---|---|---|
| 1986 | 13.0% | 5.6% | 6.8% | 86.1% | 50.1% | 2.9% | 11.9% |
| 1987 | 14.5% | 4.6% | 6.4% | 89.7% | 53.0% | 2.0% | 10.9% |
| 1988 | 15.6% | 4.4% | 6.1% | 92.1% | 37.3% | 2.6% | 10.1% |
| 1989 | 14.1% | 5.0% | 6.6% | 92.8% | 34.2% | 3.9% | 10.7% |
| 1990 | 12.9% | 4.9% | 6.2% | 90.3% | 44.2% | 5.0% | 10.6% |
| 1991 | 14.3% | 6.1% | 7.6% | 85.5% | 38.4% | 7.0% | 12.7% |
| 1992 | 14.7% | 5.8% | 7.3% | 87.5% | 40.5% | 5.4% | 11.1% |
| 1993 | 15.5% | 6.2% | 8.1% | 82.7% | 33.0% | 4.6% | 11.4% |
| 1994 | 16.9% | 5.0% | 7.4% | 88.0% | 34.2% | 4.1% | 11.6% |
| 1995 | 16.6% | 10.9% | 12.4% | 89.2% | 34.3% | 6.2% | 17.2% |
| 1996 | 15.7% | 12.7% | 13.5% | 90.8% | 30.6% | 3.7% | 16.0% |
| 1997 | 17.2% | 9.0% | 11.2% | 90.9% | 21.2% | 7.8% | 16.2% |
| 1998 | 16.0% | 9.1% | 10.9% | 90.3% | 27.4% | 7.5% | 15.9% |
| 1999 | 14.4% | 9.3% | 10.8% | 89.7% | 18.8% | 11.2% | 16.6% |
| 2000 | 13.3% | 9.8% | 11.0% | 88.7% | 18.4% | 11.8% | 16.1% |
| 2001 | 11.6% | 9.4% | 10.1% | 85.3% | 25.0% | 8.0% | 13.6% |
| 2002 | 12.3% | 8.8% | 10.0% | 90.0% | 17.0% | 7.7% | 13.9% |
| 2003 | 12.8% | 10.2% | 11.0% | 90.3% | 19.9% | 6.9% | 14.3% |
| 2004 | 14.2% | 9.4% | 11.0% | 90.4% | 16.7% | 5.6% | 13.3% |
| 2005 | 13.9% | 13.2% | 13.4% | 90.0% | 18.7% | 5.0% | 14.4% |
| 2006 | 14.3% | 10.0% | 11.2% | 90.7% | 13.0% | 3.8% | 12.9% |
| 2007 | 12.6% | 8.0% | 9.3% | 89.9% | 13.8% | 4.4% | 11.4% |
| 2008 | 11.9% | 7.0% | 8.5% | 84.9% | 20.7% | 4.1% | 11.4% |
| 2009 | 15.0% | 9.2% | 10.8% | 91.6% | 15.1% | 3.3% | 12.8% |
| Average | 14.3% | 8.1% | 9.5% | 89.1% | 28.2% | 5.6% | 13.2% |

Source: See Table 5.4.

These statistics give rise to two questions. The first is whether and how the decline in commercial fish catches has affected the number of commercial fishers in the Florida Keys. The number of Saltwater Product Licenses (SPL) in Monroe County declined by 54%, from an average of 3,123 in 1990/91-1992/93, to a 1,426 average for the three years to 2008/09 (Table 5.7). The declines also apply to some main endorsements to the main SPL; for stone crabs from 1,519 in 1990/91 to 392 in 2008/09 (-74%), and for crawfish/lobsters from 1,681 to 625 (-63%). Both of these fisheries have been subject to significant effort limitation programs (http://www.myfwc.com/RULESANDREGS/SaltwaterRules_history.htm).

In contrast, the number of endorsements for restricted species (RS) declined by only 10%, from 1,301 in 1990/91 (40% of total SPLs) to 1,172 in 2008/09 (86% of total SPLs). According to the commercial fishing regulations (FWC 2009), RS endorsement is required to sell any species designated as "reef fish", many of which require a federal permit as well. The main reason for the relative stability in RS endorsements, however, is that the number of species that require an RS in order to harvest commercially has increased over the period and now includes most species (Bill Sharp, personal communication, May 2010).

**Table 5.7: Number of Saltwater Product Licenses, commercial fishing**

| Year ended June | Monroe County | Florida State | Monroe share |
|---|---|---|---|
| 1991 | 3,186 | 20,139 | 15.8% |
| 1992 | 3,171 | 19,429 | 16.3% |
| 1993 | 3,011 | 18,762 | 16.0% |
| 1994 | 3,011 | 19,968 | 15.1% |
| 1995 | 2,940 | 19,421 | 15.1% |
| 1996 | 2,932 | 18,146 | 16.2% |
| 1997 | 2,901 | 17,575 | 16.5% |
| 1998 | 2,704 | 17,021 | 15.9% |
| 1999 | 2,560 | 16,159 | 15.8% |
| 2000 | 2,408 | 15,395 | 15.6% |
| 2001 | 2,284 | 14,880 | 15.3% |
| 2002 | 2,064 | 13,799 | 15.0% |
| 2003 | 2,012 | 13,462 | 14.9% |
| 2004 | 1,952 | 12,856 | 15.2% |
| 2005 | 1,858 | 12,501 | 14.9% |
| 2006 | 1,607 | 11,578 | 13.9% |
| 2007 | 1,445 | 11,219 | 12.9% |
| 2008 | 1,467 | 11,480 | 12.8% |
| 2009 | 1,365 | 11,259 | 12.1% |
| Average 1991-93 | 3,123 | 19,443 | 16.1% |
| Average 2007-09 | 1,426 | 11,319 | 12.6% |
| Change | -54% | -42% | -22% |

Source: FRWI, http://research.myfwc.com/features/view_article.asp?id=19224

The second question is whether commercial fisheries of spiny lobster in particular have been affected by increased competition from tourists and local recreational fishers. Table 5.8 suggests that this is probably not so. Spiny lobster fisheries in Florida (of which almost 90% is in Monroe County, as shown by Table 5.6 for commercial fisheries) have declined equally strongly for commercial and recreational fishers according to a recent FWRI presentation (Sharp 2010). While there are considerable fluctuations from year to year, the proportion of the total spiny lobster catch by recreational fishers was reasonably stable at 23-25% between the 1990s and the first decade of the 2000s, as shown by the averages at the bottom of Table 5.8.

It is more likely that juvenile populations are more affected by virus disease than in the past, and that the regional overfishing has affected recruitments – probably a combination of these factors (John Hunt, personal communication, May 2010).

**Table 5.8: Spiny lobster landings, Florida**

| Thousand pounds | Commercial fishers | Recreational fishers | Total landings | Recreational share of total |
|---|---|---|---|---|
| 1993/94 | 5,310 | 1,883 | 7,193 | 26% |
| 1994/95 | 7,182 | 1,906 | 9,088 | 21% |
| 1995/96 | 7,017 | 1,931 | 8,948 | 22% |
| 1996/97 | 7,744 | 1,923 | 9,667 | 20% |
| 1997/98 | 7,640 | 2,304 | 9,944 | 23% |
| 1998/99 | 5,448 | 1,300 | 6,748 | 19% |
| 1999/00 | 7,669 | 2,462 | 10,131 | 24% |
| 2000/01 | 5,569 | 1,950 | 7,519 | 26% |
| 2001/02 | 3,079 | 1,251 | 4,330 | 29% |
| 2002/03 | 4,577 | 1,455 | 6,033 | 24% |
| 2003/04 | 4,162 | 1,411 | 5,573 | 25% |
| 2004/05 | 5,474 | na | na | na |
| 2005/06 | 2,963 | 1,131 | 4,094 | 28% |
| 2006/07 | 4,799 | 1,305 | 6,104 | 21% |
| 2007/08 | 3,778 | 1,215 | 4,993 | 24% |
| 2008/09 | 3,269 | 1,262 | 4,531 | 28% |
| 2009/10 | 4,257 | 1,116 | 5,373 | 21% |
| Average per fishing season | | | | |
| 1993-2000 | 6,697 | 1,957 | 8,655 | 23% |
| 2001-2009 | 4,040 | 1,268 | 5,308 | 25% |

Source: Sharp (2010). Source of commercial fishing data: landings reported to the Florida Trip Information System. Recreational: from surveys of recreational lobster permit holders.

## 5.4 BIOPHYSICAL RESEARCH DIRECTIONS

This section contains a few representative examples rather than an encyclopedic description of the biology of the Florida Keys coral reefs. An overall perspective is given in Jaap et al. (2008), which is part of large publication describing all the reefs in the United States, including the Pacific and Caribbean. It also has a chapter on the importance of studying the paleoclimate in the Keys (Lidz et al. 2008), the "quaternary" perspective advocated by Precht and Miller (2007).

The Fish and Wildlife Research Institute (FWRI) in Marathon conducts biophysical research focused on Florida Keys issues. The FWRI takes two approaches: research into fisheries and related matters including programs focusing on lobsters and finfish, and building science relating to the ecosystem services of the Florida Keys, through surveying, monitoring, and devising conceptual models of the marine ecosystem. The latter approach delivers fisheries-dependent programs providing size and other structural data on landings.

Examples of the fisheries and related research follow, dealing with research into seagrass habitats, spiny lobsters, and the queen conch, and into strategic planning for the Florida Bay. As noted above, the aim is to provide a general rather than comprehensive impression of research undertaken by the FWRI and others that remains vitally important in the build-up of knowledge in a time threatened by rapidly changing climatic conditions.

### 5.4.1 Seagrass beds

The general objective of seagrass monitoring in the Sanctuary is to measure the status and trends of seagrass communities to evaluate how best to protect and restore the living marine resources. “The scope and depth of this monitoring effort are without precedent or peer for seagrass ecosystems throughout the world.” (Fourqurean 2009)

Many studies in the Caribbean have documented the ecological importance of seagrass beds and mangroves as nursery areas for reef fishes of recreational and commercial importance. “Describing the relationship between seagrass habitats and fish assemblages, especially in environmentally sensitive areas such as the FKNMS, is critical for evaluating patterns and trends in the ecosystem and evaluating the recovery of impacted areas. .. Ultimately, managers must consider a suite of habitats that may be accommodating the life stages of a wide variety of fish species when making management decisions especially as they relate to .. establishment of protected areas.” (Acosta et al. 2007, p 16)

### 5.4.2 Spiny lobsters

The history of spiny lobster fishery in Florida, centered on the Keys, has been told up to the 1990s (Hunt 2000). During the 20th century, the fishery for spiny lobsters (*Panulirus argus*) evolved from small undercapitalized operations to a large, economically important, heavily capitalized fishery. The growth evoked considerable management concern and controversy, especially during the 1980s and 1990s.

This led to the Lobster Trap Certification Program, entered into the Florida Statutes in 1992. In that year, commercial fisheries covered the Gulf and Atlantic waters of the Florida Keys and along the east coast north to the Palm Beach area. The fishing effort also extended west of the Dry Tortugas, where the mean carapace length was 114.9 mm, about 30 mm more than the mean size from the rest of the fishery.

The trap certification program in 1992 established an individual transferable certificate for the use of a trap, developed a formula to set the initial allocation of certificates, and established that the management objective of the program was to reduce the total number of traps.

The primary prediction was that lobster landings would remain cyclically stable as trap numbers decreased, that the season length might increase, and the number of sublegal lobsters in traps might decrease, ameliorating any impacts of fishing practices in the absence of active measures to reduce sublegal lobster mortality. However, commercial fishers expressed concern that recreational fishers might reap most of the benefit of increased lobster availability as trap numbers declined.

Referring back to the statistics in the previous section, spiny lobster landings have declined since the 1990s, but not as much as most other catches (Table 5.5). Recreational fishers have not taken an increased share of total catches (Table 5.8).

A recent study has provided the first quantitative biogeographic description of hardbottom communities of the Florida Keys, confirming the suspected relationship between the structural features of hardbottom habitat and their value as nurseries for juvenile spiny lobster (Bertelsen et al. 2009). Hardbottom habitat constitutes a large proportion of the coastal waters of South Florida, but it is a chronically understudied feature of the marine seascape in this region.

The study estimated the relative bottom coverage of vegetation (seagrass and macroalgae) and the abundance of sponges, corals and other crevice-bearing structures, as well as the abundance of juvenile lobsters. The relationship between habitat and size-specific juvenile lobster abundance was estimated using a multivariate statistical approach. Branching-candle sponges and octocorals tended to be under-used by lobsters compared to preferred loggerhead sponges, coral heads, and solution holes which were used more frequently. As the lobsters grew, they changed their shelter preference.  Small juveniles tended to occupy a variety of sponges, whereas large juveniles preferred hard structures such as coral heads and solution holes.

Like most coastal habitats, hardbottom is threatened by a variety of environmental perturbations, most of which are of human origin. Impacts on the abundance of lobster have been documented on hardbottom areas in Florida affected by siltation. Declining water quality and harmful algal blooms are the suspected culprits that have triggered massive die-offs of sponges in the Florida Keys and wholesale reconfiguration of impacted hardbottom areas. Commercial fishing removes approximately seven million sponges from shallow hardbottom habitat in the Florida Keys each year, with unknown consequences, but the indirect effects of other fishing activities may be more severe (p 309).

### 5.4.3 Queen conch

In Florida, the fishery for queen conch (*Strombus gigas* L.) has been closed since 1986 due to declines attributed in part to habitat degradation and overfishing. In the late 1990s, a study of tagged conchs showed a variety of habitat preferences, from having strong preferences for coarse sand and avoiding rubble, to showing no habitat preferences  (Glazer and Kidney 2004).

Two separate conch populations were studied in parallel between 2004 and 2008: one near-shore, the other offshore. In the offshore situation, reproduction proceeds fairly normally, but not in the near-shore position. A number of genes have been identified that differ between conch in the near-shore and offshore zones (Glazer et al. 2008).

There may be a connection between climate change and reproductive behavior with conchs in different locations being affected differently by temperature change and light conditions, affecting their genetic setup and how this translates to population increase (Bob Glazer, personal communication, August 2009).

### 5.4.4 Importance of Florida Bay

Florida Bay is of particular interest for a number of reasons, including its connections to the mainland Everglades National Park as well as the Florida Keys ecosystem.

The bay includes more than 200 small islands, many of which are rimmed with mangroves. Florida Bay supports numerous protected species, and provides critical habitat for commercially important species, such as spiny lobsters, stone crabs, and many important finfish species. It also serves as the principal nursery for the offshore Tortugas pink shrimp, which supports an important fishery (Hunt and Nuttle 2007, p 1).

This report is an example of the FWRI's second approach, which relates to the ecosystem aspects of the Florida Keys. It documents the progress made towards the objectives established in the 1997 Florida Bay Strategic Plan. The inception of the Comprehensive Everglades Restoration Plan (CERP) in 2000 signals a shift in resource management away from the reactive stance of protecting natural resources toward the proactive pursuit of restoring south Florida's ecosystems. In general, ecosystem restoration challenges us to look ahead.

The report identifies a number of issues:

- The alarming ecosystem changes occurring in the Florida Bay in the 1980s and 1990s which led to the CERP
- The main external factors that control the movement of water and solutes within Florida Bay and their exchange with the Everglades and adjacent marine systems
- External sources of nutrients and their effect on water quality
- Plankton blooms
- Seagrass ecology, since seagrasses account for a major portion of the primary production in the Florida Bay ecosystem.

### 5.4.5 Overfishing reef fish

Jerald Ault, James Bohnsack, Jiangang Luo and Steven Miller have often joined forces along the lines of Miller's cooperation with Mark Chiappone described in Section 5.2. Two papers in 2005 concerned overfishing, especially of members of the "snapper-grouper reef fish complex." The first FKNMS management plan in 1996 noted that the Florida Keys reef ecosystem is considered one of the nation's most significant and most stressed marine resources. There is much to lose as the Florida Keys have more than 500 fish species, including almost 400 that are reef-associated, and thousands of invertebrates, including corals, sponges, shrimps, crabs, and lobsters.

The goods and services of the ecosystem are threatened by increased exploitation and environmental changes from a rapidly growing regional human population. The snapper-grouper fishery in the Florida Keys is experiencing overfishing and stocks are being overfished relative to established benchmarks for resource sustainability (Ault et al. 2005a).

Reef fisheries target the snapper-grouper complex. Species utilize a mosaic of cross-shelf habitats and oceanographic features over their life spans. Different snapper and grouper species use different habitats and spawning grounds, adding to the ecological complexity and exacerbating the risks of overfishing.

In the interest of future prospects for sustainable fisheries, the authors noted (p 617): "An immediate priority is to reduce fishing mortality rates in the Florida coral reef ecosystem to levels that ensure long-term fishery sustainability and productivity. Whether stocks decline from fishing or detrimental environmental changes, the appropriate fishery policy choice is the same: reduce fishing pressure."

Using length as a measure of exploitation rates can be deceptive. The impact of exploitation is more severe for the slow-growing, long-lived groupers and hogfish than for other members of the snapper-grouper complex. In addition, exploitation rates appear to differ throughout Florida, but are most intense in the Florida Keys. Because of these factors, management to build sustainable fisheries may need to consider the entire reef-fish complex and perhaps invoke a spatial context to interventions. (Ault et al. 2005b, p 422)

# 6 SOCIOECONOMIC AND RELATED INDICATORS

## 6.1 ECONOMIC TRENDS

The United States benefits from a set of centralized statistics ranging from national to county level, compiled by the Bureau of Economic Analysis (BEA) of the Department of Commerce. Some data are compiled by other agencies, but the BEA framework provides some assurance that the information is generally internally consistent, and it is the source of the tables following. Tourism data are the subject of Section 6.2, while the physical data for commercial fisheries were shown in the previous chapter (Section 5.3).

### 6.1.1 POPULATION

Table 6.1 puts the surrounding demographic environment into perspective. While the total US population has grown at relatively modest rates – at 1.1% per annum between 1969 and 2008 and a similar rate (1.0%) in the more recent past from 1999 – Florida's growth was much higher over the full forty years (2.7% pa), though it has slowed down to 1.8% over the past decade. The population growth in the South Florida Metropolitan Area (Miami-Dade, Broward and Palm Beach Counties) was actually less than in the State as a whole: 2.4% pa over the long period, and slowing to only 1.2% pa between 1999 and 2008.

**Table 6.1: Population trends, South Florida Metropolitan Area versus USA and total Florida**

| Million | USA | Florida | South Florida | FL/US | SFL/FL |
|---|---|---|---|---|---|
| 1969 | 201.3 | 6.64 | 2.18 | 3.3% | 32.9% |
| 1979 | 224.6 | 9.47 | 3.12 | 4.2% | 33.0% |
| 1989 | 246.8 | 12.64 | 3.98 | 5.1% | 31.5% |
| 1999 | 279.0 | 15.76 | 4.93 | 5.6% | 31.3% |
| 2000 | 282.2 | 16.05 | 5.03 | 5.7% | 31.3% |
| 2001 | 285.1 | 16.35 | 5.12 | 5.7% | 31.3% |
| 2002 | 287.8 | 16.68 | 5.21 | 5.8% | 31.3% |
| 2003 | 290.3 | 16.98 | 5.28 | 5.8% | 31.1% |
| 2004 | 293.0 | 17.38 | 5.36 | 5.9% | 30.9% |
| 2005 | 295.8 | 17.78 | 5.44 | 6.0% | 30.6% |
| 2006 | 298.6 | 18.09 | 5.47 | 6.1% | 30.2% |
| 2007 | 301.6 | 18.28 | 5.47 | 6.1% | 29.9% |
| 2008 | 304.4 | 18.42 | 5.50 | 6.1% | 29.9% |
| Annual change | | | | | |
| 1969-2008 | 1.1% | 2.7% | 2.4% | | |
| 1999-2008 | 1.0% | 1.8% | 1.2% | | |

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

The South Florida Metropolitan Area relative to the total State population fell from 33% in the 1970s to 31.3% at the turn of the century, and was just below 30% in 2008. Meanwhile, the Combined Statistical Area of which Orlando is part (Orlando-Deltona-Daytona Beach) grew from 696,300 in 1969 to 2.7 million in 2008, increasing its share of the total population in Florida from 10.5% to 14.8% (more percentage points than South Florida lost).

| Table 6.2: Monroe County population trends | | | | |
|---|---|---|---|---|
| Persons | Population | Annual change | Monroe /Florida | Monroe /SFL |
| 1969 | 52,471 | | 0.79% | 2.40% |
| 1979 | 64,586 | 2.1% | 0.68% | 2.07% |
| 1989 | 77,058 | 1.8% | 0.61% | 1.93% |
| 1990 | 78,239 | 1.5% | 0.60% | 1.92% |
| 1991 | 78,991 | 1.0% | 0.59% | 1.89% |
| 1992 | 79,676 | 0.9% | 0.58% | 1.87% |
| 1993 | 82,182 | 3.1% | 0.59% | 1.89% |
| 1994 | 81,594 | -0.7% | 0.57% | 1.84% |
| 1995 | 81,461 | -0.2% | 0.56% | 1.79% |
| 1996 | 81,358 | -0.1% | 0.55% | 1.75% |
| 1997 | 80,925 | -0.5% | 0.53% | 1.70% |
| 1998 | 80,840 | -0.1% | 0.52% | 1.67% |
| 1999 | 79,973 | -1.1% | 0.51% | 1.62% |
| 2000 | 79,483 | -0.6% | 0.50% | 1.58% |
| 2001 | 79,105 | -0.5% | 0.48% | 1.54% |
| 2002 | 78,963 | -0.2% | 0.47% | 1.51% |
| 2003 | 78,880 | -0.1% | 0.46% | 1.49% |
| 2004 | 77,901 | -1.2% | 0.45% | 1.45% |
| 2005 | 76,135 | -2.3% | 0.43% | 1.40% |
| 2006 | 74,104 | -2.7% | 0.41% | 1.36% |
| 2007 | 73,420 | -0.9% | 0.40% | 1.34% |
| 2008 | 73,298 | -0.2% | 0.40% | 1.33% |

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

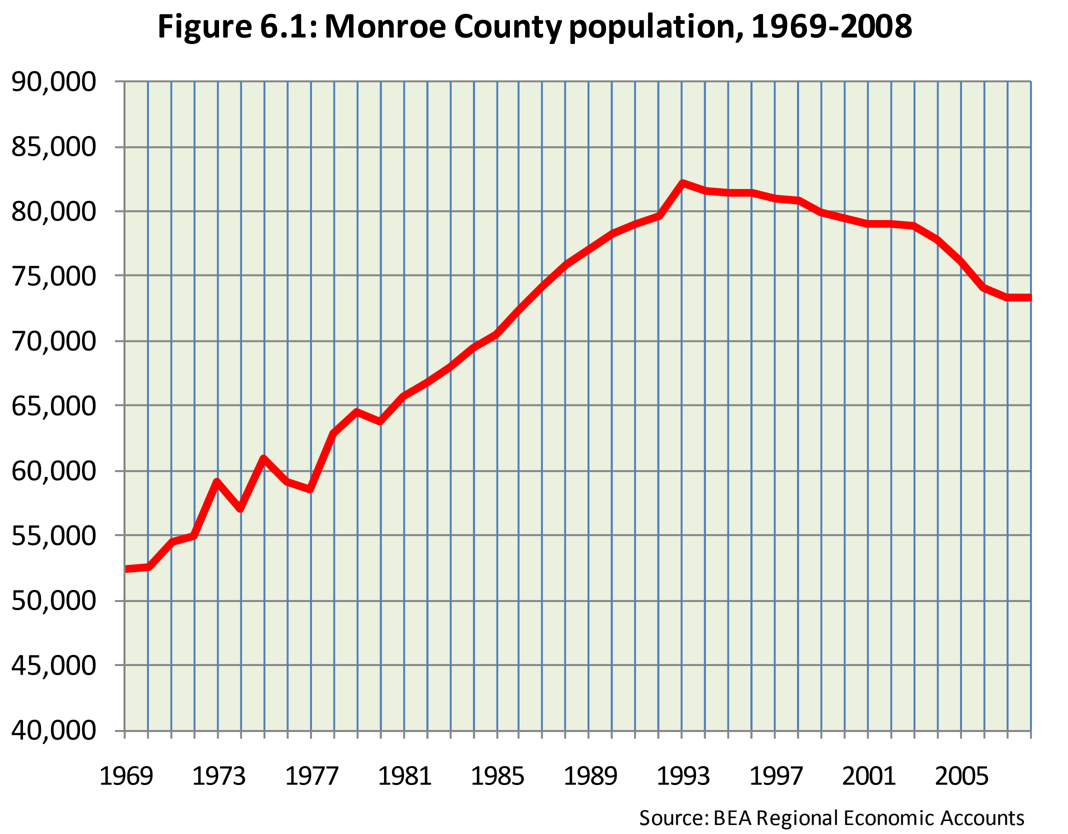
Though Miami and the other parts of the South Florida Metropolitan Area have been losing share of the total population in the State, 5.5 million is still a formidable presence for tiny Monroe County to have just north of its border (Table 6.2). While its population increased quite significantly (1.9% pa) between 1969 and 1993, when its reached its peak of more than 82,000 residents, the County still lost share of both the total Floridian population and the South Florida Metropolitan Area during that period.

Since 1993, this trend has intensified, as population numbers in Monroe County began moving backwards every year, especially since 2003 and 2004.

The interruption to the historical growth, while understandable in terms of environmental stress and associated carrying capacity, is nevertheless remarkable (Figure 6.1). The growth phase over at least 24 years covering the period for which the BEA has posted data on the Internet was quite steady, projecting the total population from 52,400 in 1969 to 82,200 in 1993. The average rate of decline over the 15 years to 2008 was 0.8%, though not as steady as the preceding growth phase. It has taken the ratio of Monroe County's population to the population of Miami-Dade, Broward and Palm Beach Counties to a new low of 1.33%, from 2.4% in 1969 through 1.9% when Monroe's population peaked in 1993.

### 6.1.2 Economic growth

The macroeconomic environment provided by the total United States and Florida is expressed by the GDP and the Gross State Product (GSP), respectively. The statistics in Table 6.3 do not include the recession year of 2009, but even before then Florida suffered negative growth – a marginal decline in real terms in 2007 and a further 1.6% loss in 2008. The US economy slowed to 0.7% growth in 2008, in constant values.




Despite the decline in 2007 and 2008, the level of real GSP in 2008 relative to 1997 implied an annual growth rate for Florida of 3.5%, compared with 2.7% pa for the United States. Until fairly recently, the performance of the fourth-largest State to which the Florida Keys are literally an appendage has, for better or worse, been one of positive growth. This is so at

**Table 6.3: GDP United States and Gross State Product Florida**

| $billion | United States | | | Florida | | |
|---|---|---|---|---|---|---|
| | Current prices | 2000 dollars* | Deflator | Current prices | 2000 dollars* | Deflator |
| 1997 | 8,238 | 8,621 | 95.6 | 391 | 415 | 94.4 |
| 1998 | 8,680 | 9,005 | 96.4 | 417 | 436 | 95.8 |
| 1999 | 9,201 | 9,404 | 97.8 | 443 | 453 | 97.6 |
| 2000 | 9,749 | 9,749 | 100.0 | 471 | 471 | 100.0 |
| 2001 | 10,058 | 9,837 | 102.3 | 497 | 485 | 102.6 |
| 2002 | 10,398 | 9,982 | 104.2 | 523 | 497 | 105.1 |
| 2003 | 10,886 | 10,226 | 106.5 | 559 | 520 | 107.4 |
| 2004 | 11,607 | 10,580 | 109.7 | 607 | 549 | 110.7 |
| 2005 | 12,339 | 10,912 | 113.1 | 670 | 589 | 113.7 |
| 2006 | 13,091 | 11,219 | 116.7 | 721 | 614 | 117.6 |
| 2007 | 13,716 | 11,439 | 119.9 | 742 | 613 | 121.0 |
| 2008 | 14,166 | 11,524 | 122.9 | 744 | 603 | 123.3 |

* Billions of chained dollars at 2000 values.

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

least according to the conventional economic growth data, which make no allowance for the real cost of ecosystem services.

**Table 6.4: Gross State Product and Personal Income**

| $ billion | GSP Florida | Personal income | | |
|---|---|---|---|---|
| | | Florida | Monroe | Monroe/FL |
| 1990 | 329.5 | | | |
| 1991 | 330.6 | | | |
| 1992 | 341.5 | | | |
| 1993 | 353.2 | | | |
| 1994 | 367.4 | | | |
| 1995 | 379.9 | | | |
| 1996 | 398.6 | | | |
| 1997 | 414.7 | 400.9 | 2.61 | 0.65% |
| 1998 | 435.6 | 427.8 | 2.83 | 0.66% |
| 1999 | 453.3 | 441.1 | 2.81 | 0.64% |
| 2000 | 471.3 | 466.6 | 3.02 | 0.65% |
| 2001 | 484.9 | 475.2 | 2.93 | 0.62% |
| 2002 | 497.3 | 483.7 | 2.88 | 0.59% |
| 2003 | 520.4 | 494.5 | 2.92 | 0.59% |
| 2004 | 548.6 | 526.4 | 3.19 | 0.61% |
| 2005 | 589.3 | 557.0 | 3.40 | 0.61% |
| 2006 | 613.6 | 587.1 | 3.65 | 0.62% |
| 2007 | 613.4 | 589.9 | 3.73 | 0.63% |
| 2008 | 603.5 | 583.7 | 3.68 | 0.63% |

Note: Small discrepancy in 1990 GSP (going from SIC to NAICS basis) used to adjust previous SIC statistics. - Personal income correlated with GSP since 1997 but previously higher, and suggesting unrealistically low growth rate for Florida. Monroe personal income series probably correlated with GSP from 1997, via total state personal income.

Source: BEA Regional Economic Accounts, at constant 2000 price dollars (http://www.bea.gov/regional/).

Estimates of economy-wide GDP and GSP statistics do not go as far as to county level, but personal income statistics do, though they appear to be compatible only since about 1997 (Table 6.4). Comparing 2008 with 1990 shows an average annual increase of 3.4% for Florida and almost the same rate for 1997-2008 (3.5% pa), during which period the personal income in Monroe County increased by 3.2% pa.

This differs from the population statistics in Table 6.2 which show continued falls from 1993. The difference is probably attributable to influx of wealthy people, as discussed in the scenario-planning workshops in 2008 (Appendix 2). Other statistical evidence shows that structural change is actually happening (see below).

### 6.1.3 Employment patterns

Total employment increased in Florida from an average of less than 2.9 million between 1969 and 1973, to 7.8 million in 1994-98 and 10.4 million in 2008 (Table 6.5). This is equivalent to an annual rate of 4.1% in the first period to 1994-98 and 2.6% between 1994 and 2008. The equivalent figures for Monroe County were 2.8% and 1.6% per annum, respectively. The increase continued despite the population decline in the County.

**Table 6.5: Total employment, Florida and Monroe County**

| Thousand persons | Florida | Monroe | Monroe/FL |
|---|---|---|---|
| Average 1969-73 | 2,857 | 24.7 | 0.9% |
| Average 1974-78 | 3,868 | 28.4 | 0.7% |
| Average 1979-83 | 4,826 | 34.5 | 0.7% |
| Average 1984-88 | 5,955 | 40.0 | 0.7% |
| Average 1989-93 | 6,764 | 44.0 | 0.7% |
| Average 1994-98 | 7,754 | 49.0 | 0.6% |
| 1994 | 7,234 | 46.1 | 0.6% |
| 1995 | 7,494 | 47.5 | 0.6% |
| 1996 | 7,740 | 48.7 | 0.6% |
| 1997 | 8,005 | 50.5 | 0.6% |
| 1998 | 8,298 | 52.2 | 0.6% |
| 1999 | 8,567 | 51.9 | 0.6% |
| 2000 | 8,842 | 53.1 | 0.6% |
| 2001 | 8,917 | 53.8 | 0.6% |
| 2002 | 9,056 | 53.8 | 0.6% |
| 2003 | 9,286 | 55.1 | 0.6% |
| 2004 | 9,662 | 55.0 | 0.6% |
| 2005 | 10,088 | 55.5 | 0.6% |
| 2006 | 10,407 | 56.0 | 0.5% |
| 2007 | 10,553 | 56.3 | 0.5% |
| 2008 | 10,424 | 57.9 | 0.6% |

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

The high employment level in Monroe County is striking. In 2008, 57,900 persons were recorded as working there, while the total population had declined to 73,300. The ratio of employment to population was 79%, compared with 56.5% in total Florida, which is a more normal" workforce ratio. The reason is the number of Hispanic and other people who work in Monroe County in the hospitality and retail industries in particular, but live elsewhere.

Table 6.6 shows that accommodation and food services, and retail trade, are indeed the main industries in the Keys (which have little manufacturing industry and no agriculture). The hospitality industry accounted for 10,600 of the total 58,000 persons working in the Keys in 2008 – though the number has declined from 11,600 since 2001. Retail trade employed 6,500, again a decline, from 6,900 in 2001.

The third-most important industry is real estate, which in contrast to the two top employing industries has been growing strongly, from 3,000 in 2001 to 5,000 in 2008. This may be associated with the structural change to which many participants in the scenario-planning workshops in 2008 referred. Younger people and others are moving out, and absentee landlords are moving in, buying residential properties which they occupy at most on a part-time basis.

**Table 6.6: Employment by industry in Monroe County, 2001-2008, compared with Florida**

| Employment category, persons | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| Private employment | 46,180 | 46,058 | 47,195 | 47,125 | 47,727 | 48,248 | 48,577 | 50,187 |
| *of which* | | | | | | | | |
| Accommodation and food services | 11,644 | 10,964 | 11,325 | 11,434 | 10,737 | 10,000 | 9,894 | 10,617 |
| Retail trade | 6,932 | 6,823 | 6,694 | 6,646 | 6,659 | 6,782 | 6,642 | 6,496 |
| Real estate, rental and leasing | 2,994 | 3,170 | 3,630 | 4,103 | 4,639 | 4,797 | 4,525 | 5,024 |
| All other private employment | 21,570 | 20,957 | 21,649 | 22,183 | 22,035 | 21,579 | 21,061 | 22,137 |
| Government and government enterprises | 7,668 | 7,753 | 7,868 | 7,871 | 7,766 | 7,733 | 7,772 | 7,741 |
| *of which* | | | | | | | | |
| Federal civilian | 1,252 | 1,278 | 1,331 | 1,263 | 1,193 | 1,130 | 1,137 | 1,183 |
| Military | 1,555 | 1,675 | 1,724 | 1,730 | 1,697 | 1,686 | 1,670 | 1,647 |
| State | 763 | 741 | 747 | 750 | 721 | 684 | 678 | 666 |
| Local | 4,098 | 4,059 | 4,066 | 4,128 | 4,155 | 4,233 | 4,287 | 4,245 |
| Total private and government employment | 53,848 | 53,811 | 55,063 | 54,996 | 55,493 | 55,981 | 56,349 | 57,928 |

| Relative to total employment | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| Private employment | 85.8% | 85.6% | 85.7% | 85.7% | 86.0% | 86.2% | 86.2% | 86.6% |
| *of which* | | | | | | | | |
| Accommodation and food services | 21.6% | 20.4% | 20.6% | 20.8% | 19.3% | 17.9% | 17.6% | 18.3% |
| Retail trade | 12.9% | 12.7% | 12.2% | 12.1% | 12.0% | 12.1% | 11.8% | 11.2% |
| Real estate, rental and leasing | 5.6% | 5.9% | 6.6% | 7.5% | 8.4% | 8.6% | 8.0% | 8.7% |
| All other private employment | 40.1% | 38.9% | 39.3% | 40.3% | 39.7% | 38.5% | 37.4% | 38.2% |
| Government and government enterprises | 14.2% | 14.4% | 14.3% | 14.3% | 14.0% | 13.8% | 13.8% | 13.4% |
| *of which* | | | | | | | | |
| Federal civilian | 2.3% | 2.4% | 2.4% | 2.3% | 2.1% | 2.0% | 2.0% | 2.0% |
| Military | 2.9% | 3.1% | 3.1% | 3.1% | 3.1% | 3.0% | 3.0% | 2.8% |
| State | 1.4% | 1.4% | 1.4% | 1.4% | 1.3% | 1.2% | 1.2% | 1.1% |
| Local | 7.6% | 7.5% | 7.4% | 7.5% | 7.5% | 7.6% | 7.6% | 7.3% |
| Total private and government employment | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

| Distribution in total Florida | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| Private employment | 86.5% | 86.6% | 86.7% | 87.1% | 87.5% | 87.7% | 87.7% | 87.6% |
| *of which* | | | | | | | | |
| Accommodation and food services | 7.4% | 7.5% | 7.5% | 7.6% | 7.6% | 7.6% | 7.6% | 7.7% |
| Retail trade | 12.1% | 11.9% | 11.6% | 11.5% | 11.4% | 11.3% | 11.3% | 11.1% |
| Real estate, rental and leasing | 3.9% | 4.1% | 4.3% | 4.7% | 5.2% | 5.5% | 5.4% | 5.8% |
| All other private employment | 63.1% | 63.1% | 63.2% | 63.3% | 63.4% | 63.4% | 63.5% | 63.0% |
| Government and government enterprises | 12.5% | 12.4% | 12.3% | 12.0% | 11.7% | 11.5% | 11.5% | 11.6% |
| *of which* | | | | | | | | |
| Federal civilian | 1.3% | 1.3% | 1.4% | 1.3% | 1.3% | 1.2% | 1.2% | 1.2% |
| Military | 1.2% | 1.2% | 1.2% | 1.1% | 1.0% | 1.0% | 1.0% | 1.0% |
| State | 2.5% | 2.3% | 2.2% | 2.2% | 2.1% | 2.0% | 1.9% | 1.9% |
| Local | 7.5% | 7.6% | 7.6% | 7.5% | 7.3% | 7.3% | 7.3% | 7.4% |
| Total private and government employment | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

Private employment accounted for about 86% of total employment in Monroe County between 2001 and 2008. Employment by government and government enterprises remained fairly constant numerically, with civilian federal institutions declining and being outnumbered by the military in their Key West establishments. The largest employment group was local government with over 4,200 employees in 2008. State government employment in Monroe County was relatively small, and declining.

The bottom panel of Table 6.6 provides a basis for comparing the employment pattern in Monroe County with total Florida. It is strikingly different for accommodation and food services (18.3% of employees in Monroe County, 7.7% in Florida). Retail trade held similar shares in Florida and the Keys, and real estate, while increasing its share both statewide and in Monroe County, by 2008 had grown to account for 8.7% of all employment in the County compared with 5.8% in total Florida.

Federal employment, in particular the military, was a relatively stronger presence in Monroe County than in Florida as a whole. State employees were relatively low in numbers in Monroe County (the seat of government is elsewhere), while the representation of local government employees was on a par with the State average.

## 6.2 Tourism

The Key West Chamber of Commerce publishes a monthly set a statistical indicators that give a picture of tourism and recreation activities, though some of these indicators have to be treated with caution as discussed below. The ultimate sources from which the Chamber compiles the data include Monroe County, the Key West Port Authority, the Key West International Airport, and the Florida Department of Revenue.

**Table 6.7: Monroe County Bed Tax, Key West**

| $ '000 | At current prices | CPI deflator | At constant 2000 prices | Change on last year |
|---|---|---|---|---|
| 1995 | 4,392 | 152.4 | 6,182 | |
| 1996 | 4,893 | 156.9 | 6,689 | 8.2% |
| 1997 | 5,341 | 160.5 | 7,138 | 6.7% |
| 1998 | 5,352 | 163.0 | 7,043 | -1.3% |
| 1999 | 5,858 | 166.6 | 7,543 | 7.1% |
| 2000 | 6,228 | 172.2 | 7,758 | 2.9% |
| 2001 | 6,425 | 177.1 | 7,782 | 0.3% |
| 2002 | 6,420 | 179.9 | 7,654 | -1.6% |
| 2003 | 6,850 | 184.0 | 7,986 | 4.3% |
| 2004 | 7,271 | 188.9 | 8,257 | 3.4% |
| 2005 | 7,220 | 195.3 | 7,930 | -4.0% |
| 2006 | 7,421 | 201.6 | 7,896 | -0.4% |
| 2007 | 7,893 | 207.3 | 8,167 | 3.4% |
| 2008 | 8,166 | 215.3 | 8,135 | -0.4% |
| 2009 | 8,023 | 214.5 | 8,023 | -1.4% |

Fourpenny tax from June 2009 converted to previous basis.

Source: As compiled by Key West Chamber of Commerce

Monroe County in 1991 introduced a 3% bed tax (called a threepenny tax) to generate revenue from tourist expenditure at hotels, motels and other short-term lodging while having as little impact as possible on residents. The bed tax was increased to 4% from June 1, 2009, but the statistics in Table 6.7 have been adjusted back to a 3% base to provide a consistent time series.

Expressed in constant prices, using the implicit deflator from Florida's GSP calculations, revenue from the bed tax generally increased up to

2004, but has fluctuated around a static trend since then. The value of bed tax as a tourism indicator, however, is limited by factors such as the exclusion of day visitors (including a growing number of cruise ship passengers) and visitors staying with family and friends, categories that have both increased strongly since the 1990s. There has also been a strong move toward greater condominium/time share ownership among visitors, and many stay in government-owned accommodations that are not taxed or may not have been taxed throughout the whole period. Finally, compliance with the bed tax itself may have improved over the years, which could be a significant factor.

The statistics in Table 6.7 cover Key West (Monroe County District 1), which accounted for about 54% of total bed tax collections in the County between FY 2002 and 2009. It increased in FY 2009 and continued the increase in the first half of FY 2010, according to the Monroe County *Four Penny Revenue Report*. This report also shows Key West's 54% share applying through the 1990s, so the Key West bed tax trend was until recently largely representative of Monroe County as a whole for visitors staying overnight in paid accommodation, subject to the qualifications listed in the previous paragraph.

Compared with the 54%+ of total bed tax receipts from Key West, District 2 (Lower Keys)

**Table 6.8: Monroe County Bed Tax, by districts**

$thousand at average FY 2009 prices

| Fiscal year | Key West | Lower Keys | Marathon | Islamorada | Key Largo | County |
|---|---|---|---|---|---|---|
| 2002 | 7,495 | 772 | 1,897 | 1,802 | 1,997 | 13,962 |
| 2003 | 7,837 | 778 | 2,040 | 1,876 | 2,054 | 14,584 |
| 2004 | 8,267 | 868 | 2,082 | 1,968 | 2,134 | 15,320 |
| 2005 | 8,305 | 879 | 2,112 | 2,045 | 2,208 | 15,549 |
| 2006 | 7,669 | 872 | 2,159 | 1,995 | 1,998 | 14,693 |
| 2007 | 7,961 | 922 | 2,250 | 2,094 | 2,195 | 15,421 |
| 2008 | 8,221 | 848 | 1,901 | 1,911 | 2,108 | 14,989 |
| 2009 | 7,899 | 748 | 1,934 | 1,302 | 1,833 | 13,716 |

Proportion of Monroe County

| Fiscal year | Key West | Lower Keys | Marathon | Islamorada | Key Largo | County |
|---|---|---|---|---|---|---|
| 2002 | 53.7% | 5.5% | 13.6% | 12.9% | 14.3% | 100% |
| 2003 | 53.7% | 5.3% | 14.0% | 12.9% | 14.1% | 100% |
| 2004 | 54.0% | 5.7% | 13.6% | 12.8% | 13.9% | 100% |
| 2005 | 53.4% | 5.7% | 13.6% | 13.2% | 14.2% | 100% |
| 2006 | 52.2% | 5.9% | 14.7% | 13.6% | 13.6% | 100% |
| 2007 | 51.6% | 6.0% | 14.6% | 13.6% | 14.2% | 100% |
| 2008 | 54.8% | 5.7% | 12.7% | 12.7% | 14.1% | 100% |
| 2009 | 57.6% | 5.5% | 14.1% | 9.5% | 13.4% | 100% |
| Average | 53.9% | 5.7% | 13.9% | 12.6% | 14.0% | 100% |

Adjustment made for increased bed tax June-September 2009 (4/3).

Source: Monroe County Tourist Development Council, from Monroe County tax records (updated statistics from 2005 directly from Monroe County *Fourpenny Revenue Report)*. Deflated by Bureau of Labor Statistics Consumer Price Index for all urban consumers.

represents less than 6%, Districts 3 and 5 (Marathon and Key Largo) about 14% each, and District 4 (Islamorada) about 13%. There is no immediate explanation why District 4 showed a 32% decline in FY 2009 (after adjusting for the increased bed tax rate), compared with falls of 4% in Key West, 12% in Lower Keys, and 13% in Key Largo, and a rise of 2% in Marathon.

Adjusted back to a 3% tax but unadjusted for inflation, four of the five districts showed increases in the first half of FY 2010: Key West by 9%, Lower Keys 3%, Marathon 5%, and Islamorada 7%. There was a 2% decline in Key Largo, while the total adjusted bed tax for the County rose by 6%. The consumer price index rose by 1.9% in the first six months of 2010 compared with the corresponding period of 2009, suggesting that tourism, if measured by the adjusted bed tax, may be turning the corner, with Key West continuing to increase its lead but at least some recovery showing in District 4, Islamorada.

**Table 6.9: Taxable sales, Monroe County, 2003-2009**

| $million at 2000 values | Tourism & recreation | Other retail sales | Total retail sales | Commercial sales | Grand total taxable sales | *Tourism & re-creation share* |
|---|---|---|---|---|---|---|
| 2003 | 908.7 | 856.4 | 1,765.0 | 261.8 | 2,026.8 | *44.8%* |
| 2004 | 980.8 | 803.4 | 1,784.1 | 327.8 | 2,111.9 | *46.4%* |
| 2005 | 977.5 | 859.8 | 1,837.3 | 342.4 | 2,179.7 | *44.8%* |
| 2006 | 966.4 | 842.0 | 1,808.3 | 388.3 | 2,196.7 | *44.0%* |
| 2007 | 971.0 | 787.3 | 1,758.3 | 359.6 | 2,117.9 | *45.8%* |
| 2008 | 935.4 | 709.6 | 1,645.0 | 325.9 | 1,971.0 | *47.5%* |
| 2009 | 878.2 | 651.6 | 1,529.8 | 291.2 | 1,821.0 | *48.2%* |

Note: As discussed in the text, these statistics underestimate the true contribution of tourism and recreation by an estimated 25-30% above the 44-48% contribution shown in the right-hand column.

Source: As compiled by the Key West Chamber of Commerce, adjusted by implicit deflator for Florida Gross Product (2009 using closely correlated US implicit deflator).

Taxable sales data represent an attempt to identify tourism and recreation sales separately from other retail sales, and from commercial sales (Table 6.9). Between 2003 and 2009, these sales increased in 2004, remained roughly constant up to 2007 and then declined in 2008 and again in 2009. Other retail sales generally declined. The share of tourism and recreation in total taxable sales was about 44-46% between 2003 and 2007 before increasing to 48% in 2008 and 2009. This in itself marks Monroe County as a highly tourism-dependent economy, but the true contribution of tourism and recreation to the local economy is underestimated. Many other retail and commercial sales would satisfy demand by residents dependent on the tourist trade, and some represent direct sales to visitors.

Based on NOAA's authoritative visitor and resident surveys in 1995-96 and 2007-08 (reported in Table 6.26 in Section 6.4), visitor spending accounts for 60% of gross sales in Monroe County, compared with the 44-48% shown in Table 6.9.

The analysis of seasonality in Section 6.2.1 below draws attention to one of these issues, suggesting that visitors may self-cater, purchasing from local supermarkets and cooking for themselves in their resort or motel. Furthermore, analysis reported in Section 6.4.4 shows a strong increase in the number of persons owning condominiums and time-share facilities (Table 6.26). They would also self-cater to a large extent during their visits.

Other factors weaken the connection between the statistics in Table 6.9 and the true situation. For example, most but not all hotel, motel, and restaurant usage is related to tourism and recreation. The most reliable way of defining the true contribution of tourism and recreation to the Monroe County economy has been through the detailed surveys of tourists and residents in 1995-96 and 2007-08 (Section 6.4). The published regular economic indicators are just not adequate. This probably applies to other locations as well.

**Table 6.10: Passenger arrivals, Key West Airport**

| Thousand | Arrivals | Change |
|---|---|---|
| 1996 | 271.7 | |
| 1997 | 267.7 | -1.5% |
| 1998 | 257.6 | -3.8% |
| 1999 | 268.9 | 4.4% |
| 2000 | 275.4 | 2.4% |
| 2001 | 255.9 | -7.1% |
| 2002 | 259.3 | 1.4% |
| 2003 | 286.8 | 10.6% |
| 2004 | 291.5 | 1.6% |
| 2005 | 313.9 | 7.7% |
| 2006 | 276.2 | -12.0% |
| 2007 | 263.8 | -4.5% |
| 2008 | 222.2 | -15.8% |
| 2009 | 229.3 | 3.2% |

Source: As compiled by Key West Chamber of Commerce

The Key West Chamber of Commerce also compiles data on passenger arrivals at Key West International Airport (Table 6.10), which represent one of the three main modes of getting to the Keys. The others are cruise ships arriving in Key West (see below) and motoring from the north (covered by survey only).

Passenger arrivals at Key West Airport since 1996 generally stagnated until 2002 before rising to a peak of 314,000 in 2005, from which they declined to 264,000 by 2007 before plunging to below 230,000 in 2008 and 2009, presumably at least partly due to the financial crisis.

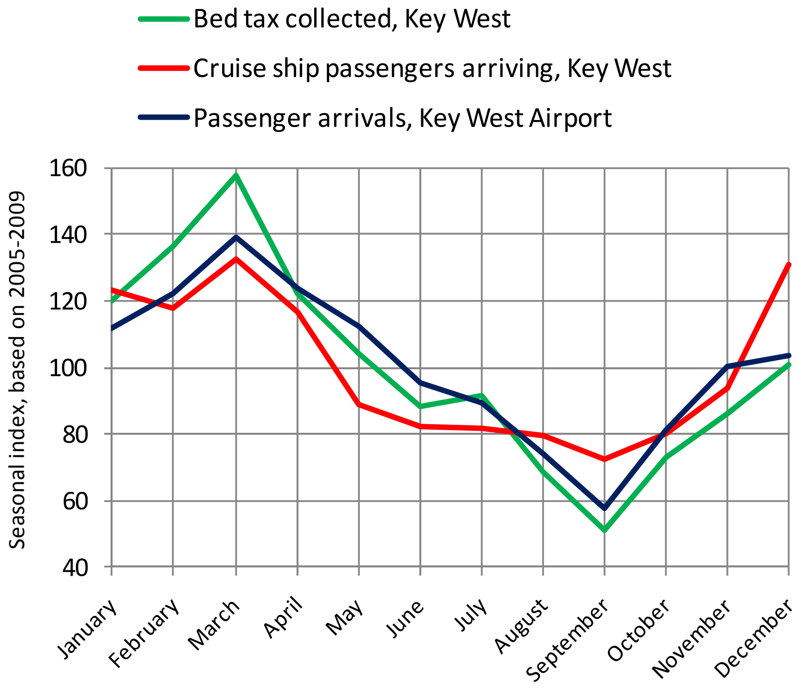
**Table 6.11: Key West cruise ship data**

| | Thousand passengers | Number of port calls | Passengers per port call |
|---|---|---|---|
| 1997 | 588.8 | 340 | 1,732 |
| 1998 | 579.5 | 404 | 1,434 |
| 1999 | 630.7 | 411 | 1,534 |
| 2000 | 656.9 | 406 | 1,618 |
| 2001 | 679.0 | 362 | 1,876 |
| 2002 | 1,030.5 | 520 | 1,982 |
| 2003 | 1,067.2 | 505 | 2,113 |
| 2004 | 934.1 | 462 | 2,022 |
| 2005 | 925.8 | 461 | 2,008 |
| 2006 | 888.2 | 425 | 2,090 |
| 2007 | 816.9 | 398 | 2,053 |
| 2008 | 739.2 | 343 | 2,155 |
| 2009 | 859.4 | 369 | 2,329 |

Source: As compiled by Key West Chamber of Commerce

Cruise ships are big business in Key West and driven by different forces from other tourism in the Keys. In each peak year of 2002 and 2003 (Table 6.11), these vessels made more than 500 port calls, delivering more than a million passengers. The pace has diminished but 859,000 passengers still arrived in 2009, from 369 port calls. There has been a rising trend in

**Figure 6.2: Seasonality of tourism indicators**




Source: Monthly statistics, Key West Chamber of Commerce

**Figure 6.3: Seasonality of taxable retail sales, Monroe County**


Source: Monthly statistics, Key West Chamber of Commerce the number of passengers per port call, from an average of 1,434 in 1998 to 2,329 in 2009, indicating that cruise ships are getting bigger.

A more recent mode of transport to the Florida Keys is by catamaran ferry from Marco Island and Fort Myers Beach on the Gulf side of southern Florida. The Key West Chamber of Commerce compilations show 68,500 passengers were ferried to Key West in 2005, rising to 88,600 in 2006 and 99,100 in 2007, before declining in 2008 (to 80,000) and 2009 (74,800).

### 6.2.1 Seasonality

Being so dependent on tourism, the Florida Keys are subject to marked seasonal fluctuations in demand. Figure 6.2 shows that bed tax collections, passenger arrivals at Key West Airport, and cruise ship passengers visiting Key West all peak in March and decline to a trough in September.

The seasonal indices used here are based on simple averages, unadjusted for upward or downward trends in the data. However, the annual average of the three indices on Figure 6.2 happens to be exactly 100, which suggests the bias is modest. In the summer season from June to November the average is 80, and in the winter season from December to May 120. In other words, the volume of tourism according to these three series is 50% higher in the winter than in the summer season.

The patterns are reflected with a month's delay in taxable tourism and recreation-related sales (Figure 6.3). The delay must be due to reporting lags, as the March peak and September trough in tourist activity are well established. Figure 6.3 also shows that while tourism and recreation-related sales have the more pronounced seasonal pattern, other retail sales retain some of the pattern, though with less amplitude. There may be a relationship between purchases by tourists and residents across the season. More likely, the boundary is blurred between tourism and recreation-related sales and other retail sales, which are not supposed to represent tourist spending – but what happens when visitors, or relatives they stay with, go to the supermarket for their cooking and other requirements?

## 6.3 Socioeconomic research projects

There has been a considerable amount of research into the socioeconomic and biophysical links in the Florida Keys, all generally classifiable under the heading of human dimensions. This section deals with research projects done elsewhere, followed by NOAA's visitor and resident surveys in Section 6.4. The problems of measuring the market and nonmarket values of the Florida Keys ecosystem are discussed in Section 6.5.

### 6.3.1 The SEFCRI report

Manoj Shivlani of the University of Miami's Rosenstiel School of Atmospheric and Marine Science is a leading researcher into the human use of Southeast Florida's coral reefs. A major report (Shivlani and Villanueva 2007) relates to the region covered by the Southeast Florida Coral Reef Initiative (SEFCRI), that is, the three counties covering the South Florida Metropolitan Area, plus Martin County to the north. The SEFCRI website provides the following explanation why it did not extend to Monroe County:

“[The SEFCRI] Team first gathered in May 2003 to develop local action strategies targeting coral reefs and associated reef resources from Miami-Dade, Broward, Palm Beach and Martin counties to improve the coordination of technical and financial support for the conservation and management of coral reefs. SEFCRI is targeting this region because the coral habitats are close to shore and co-exist with intensely urbanized areas that lack a coordinated management plan (like that of the Florida Keys National Marine Sanctuary).” (http://www.dep.state.fl.us/coastal/programs/coral/sefcri.htm)

Despite the exclusion of the Florida Keys, Manoj Shivlani’s and Maria Villanueva’s SEFCRI research provides general pointers for the Keys, though naturally there are some differences. The research is given further perspective by a presentation Shivlani gave to the Florida Reef Resilience Program (FRRP) conference reported in Section 4.2.5 (Shivlani 2008). The human dimensions of coral reef management are vitally important, he began. They include the ways individuals, groups and society interact with, affect, and are affected by the natural environment and environmental change. Relevant dimensions include:

- Half a billion people worldwide rely on coral reefs for food and income
- In the Florida Keys, commercial fisheries are closely tied to spiny lobster, reef finfish, and other species that spend part or all their life on coral reefs
- Recreational use is “over and on reefs, not always sustainably”
- In Southeast Florida, recreational users spent $2.9 billion on coral reef ecosystem-based activities in 2001
- Reefs serve essential coastline functions for humans, by providing storm damage protection and preventing coastal erosion.

Taken together, human dimensions of reef management refer to:

- Linkages between uses, valuation and perceptions of coral reef ecosystems and the resilience of coral reefs
- Relationships between the management strategies undertaken to protect coral reefs and attributes people value in coral reef ecosystems
- Responses within uses and valuation to changes in coral reefs over time
- Integration of the human and biophysical dimensions of coral reef management.

Shivlani (2008) offered the following working definition of the human dimensions of coral reef ecosystem management: “An inquiry of the linkages between the human and biophysical dimensions of reef resilience, of management strategies employed to address coral reef health, and of individuals and groups who depend on and recreate in coral reef ecosystems.”

The 200-page report (Shivlani and Villanueva 2007) compares six studies carried out for SEFCRI, based on field interviews, mail-back questionnaires and Internet surveys. The stakeholder groups were charter fishing operators, commercial fishers, dive operators, recreational anglers, researchers and managers, and surfers. Apart from surfers, these groups are also prominent in the Florida Keys, which might have benefited instead from the inclusion of cruise ships visiting Key West.

There is also a larger proportion of resident people compared with tourists than would be the case in the Keys, though the report comments in connection with one of the stakeholder groups on p 104: "The visitor base has grown considerably in the few decades since the advent of SCUBA, and diving and snorkeling activities have emerged as an important (and integrated) component of the coastal tourism economy."

The people surveyed had generally long experiences using the SEFCRI region (averaging 11-15 years or more), which increases the confidence that can be attached to their attitudes (as well as indicating that they were mainly residents rather than tourists). Most charter fishing operators, dive operators, and recreational anglers rated proximity to home or port as the main factor in choosing a particular area, and did not go far from home. Commercial fishers were the only group that rated "right conditions" above proximity, which is not surprising.

Some stakeholder groups were in conflict with others: recreational boaters conflicted with dive operators and surfers, commercial fishers with recreational anglers, and anglers with dive operators.

Conditions in most stakeholders' opinion had deteriorated, *worst* for coral reefs, moderately for water quality, fisheries and use conflicts, and least for artificial reefs.

There was general disaffection with management in the SEFCRI area which lacks a coordinated management plan (based on the evidence reported in Section 6.3.2, the Florida Keys would have done better on this score). Of a range of management options, education was the preferred or second preferred tool in all groups. Zoning and marine protected areas were not in favor among extractive user groups (charter and commercial fishers), but were preferred by dive operators, surfers, and researchers and managers. All groups were generally dissatisfied with current management, and with the option of having less management.

The worst direct impacts by users were perceived to be by sporting divers, and commercial and recreational fishers. Land-based pollution was seen as the worst indirect impact on the reefs, and global warming as the least important. "This was most likely due to respondents either not fully understanding the effects of climate change on the region (as exhibited by the high numbers of non-responses to this question) or not accepting global warming as a local impact." (Shivlani and Villanueva 2007, pp 8-9)

In conclusion, the condition of the reef resources is generally deteriorating according to users, with coral reefs (especially), fisheries and water quality all in decline, and use conflicts rising due to larger user numbers. The majority of users considered management in the SEFCRI region to be ineffective. "While there is less consensus on specific use conflicts and the relative impacts of stakeholder groups on coral reefs, the results nevertheless reveal a base of concerned users who have witnessed a pervasive decline in their local resources and who are willing to support changes in management direction to rectify current resource conditions." (p 9)

### 6.3.2 Knowledge and perceptions of FKNMS strategies and regulations

Between 2004-05 and 2007, replication studies were carried out of commercial fishers, dive operators, and members of environmental groups in the Florida Keys, all originally subjected to a baseline study in 1995-96 (Shivlani et al. 2008).

Between the survey dates in 1995-96 and 2004-05, the number of Saltwater Product License (SPL) holders in Monroe County declined strongly, as shown by Table 5.7 in the previous chapter. The fall is attributed to fishery management regulations due to overfishing and excess capacity, increased land values and competition with the tourist industry for waterfront access, and higher operating costs. Because the main loss of personnel was among younger people, the remaining fisheries workforce is more professional with older, more experienced fishers, fewer part-time fishermen, more highly capitalized (more boats, equipment and gear, primarily traps), more dependent on fishing for their personal income, and more affiliated with group organizations to represent their interests.

In 1996, there were 75 dive operators in Monroe County. This increased to 89 in 2006, but some operators in 1996 had closed and new ones had opened, so only 30 of the 69 dive operators surveyed in 2006 had also been surveyed in 1996. Consequently the make-up of the dive operators has changed somewhat over the 10-year period, which (as for the fishers) may explain some of the changes in attitudes and perceptions found in the study.

Only two local environmental groups were included in both years: Last Stand and Reef Relief (the latter has since spread geographically beyond the Keys). The third original group, the Sanctuary Friends of the Florida Keys, had not been in existence for a few years in 2007; a more recently formed group called the Sanctuary Friends Foundation of the Florida Keys chose not to participate (Shivlani et al. 2008, p 108).

As well as the new Friends group, other influential local environmental groups were not included, such as Green Living and Energy Education (GLEE), which was founded in 2003. It is unclear why environmental groups had to be represented in both surveys since this criterion evidently didn't apply to dive operators, of whom most of those interviewed in 2006 were not surveyed in 1996. With all respect to the environmental groups that were represented, the study does not reflect that local environmental groups have in all probability gained considerable influence since the 1990s.

Apart from the above structural information on commercial fishers, dive operators, and environmental groups, the replication study is obviously useful for the detail it supplies for the FKNMS Socioeconomic Research and Monitoring Program. Key findings for each of the three stakeholder groups included (Shivlani et al. 2008, p ii):

**All three groups**

- Stakeholder attitudes, perceptions and beliefs about FKNMS outcomes and support for the FKNMS have converged.
- Either a majority or plurality of all three user groups believes that the FKNMS has benefited both the environment and economy of the Florida Keys.

- None of the user groups believe that the FKNMS zones have been effective in restoring coral reefs in the Florida Keys to what they used to be, but they understand that the conditions of the reefs are driven by many factors outside the control of the FKNMS.
- Either a majority or plurality of each of the three user groups support the FKNMS zones as currently established, except commercial fishers for the Ecological Reserves (ERs).
- Across all three user groups, only two of eight items assessed were rated as having improved in condition since the establishment of the FKNMS ("mooring buoys" and "vessel groundings"). The avoidance of vessel groundings was one of the main motivations for creating the FKNMS.
- The items that were not rated as having improved were "water quality", "land-based pollution/sewage", "sea-based pollution/marine debris", "coral reefs", "seagrasses", and "fisheries". However, no resource condition was rated as having gotten worse by any of the three user groups since the establishment of the FKNMS. Most items received scores in the neutral or no change range.

**Commercial fishing community**

- There was greater support for FKNMS across a variety of aspects, with a shift from a highly negative position to majority/plurality support.
- There has been a significant shift by commercial fishers over the 10-year period towards support for the FKNMS zones; however, a plurality still does not support the ERs.
- An overwhelming majority of commercial fishers is against any more FKNMS zones of any type.

**Dive operators**

- There has been increased use of the FKNMS zones by dive operators, especially the Sanctuary Preservation Areas (SPAs).
- A majority or plurality of dive operators support more FKNMS zones of all types.
- A majority of dive operators believes that the SPAs have reduced conflicts between user groups. This was a significant change from expectations in the baseline.

**Local environmental groups**

- Based on the study, there is a need for greater outreach and education efforts to members.
- As for dive operators but not commercial fishers, members of environmental groups support more FKNMS zones of all types.

### 6.3.3 The UMASS Amherst studies

Three parallel studies of recreational fishers, snorkelers, and SCUBA divers were carried out in 2006-07 for the Florida Reef Resilience Program (FRRP) by the Human Dimensions of Marine and Coastal Ecosystems Program of the University of Massachusetts Amherst (Loomis et al. 2008a,b,c). The frame of reference was related to coral reef resilience as follows (pp vii-viii):

- **Resilience:** The ability of systems to absorb disturbances, to resist phase shifts, and to regenerate and reorganize in order to maintain key functions and processes in a time span relevant to resource use and management

- **Human dimensions of coral reef management:** An area of investigation which attempts to describe, predict, understand and affect human thought and action toward coral reefs and their associated environments.

- **Human dimensions of reef resilience:** The scientific investigation of the linkages between reef resilience, the management strategies employed to improve the health of coral reefs, and individuals and groups who depend on and enjoy coral reef environments.

These surveys provide valuable pointers to the future through comprehensive profiles of the three user groups (resident and non-resident anglers, snorkelers, and divers), including the length of their experience which proved a powerful variable in the South Florida SEFCRI report (Shivlani and Villanueva 2007). Three tables showing specific results from the three user groups show the scope of this research.

Asked about the impact on the ecological health of coral reefs in the Florida Keys (Table 6.12), residents rated climate change worst, ahead of hurricanes and commercial fishing. Impact from water quality was next, and scuba diving and snorkeling would have the least impact. Visitors thought the worst impact would be hurricanes, followed by commercial fishing and then climate change. Water quality would be the most beneficial impact. However, using a seven-point scale with 4 being neutral meant that residents rated all impacts negative on average, and visitors fell short of an average of four on all criteria except water quality, despite their generally higher scores.

The current ecological health of the Keys coral reefs was rated poor by 22.8% of all residents surveyed (average of the three resident groups in Table 6.13), compared with only 4.9% of visitors. On average, residents rated reef health only slightly above fair (the mean of 2.33 for the three groups being one-third from fair moving towards good), whereas the central tendency for the three groups of visitors was close to “good” with an overall mean of 2.92.

**Table 6.12: Impact on ecological health of Florida Keys coral reefs**

| Mean Score | Recreational fishers | | Snorkelers | | Scuba divers | |
|---|---|---|---|---|---|---|
| | Residents | Visitors | Residents | Visitors | Residents | Visitors |
| Water quality | 3.23 | 4.12 | 3.00 | 4.41 | 2.86 | 4.24 |
| Scuba diving | 3.43 | 3.54 | 3.57 | 3.96 | 3.80 | 4.09 |
| Commercial fishing | 2.66 | 2.54 | 2.74 | 2.85 | 2.97 | 2.97 |
| Hurricanes | 2.80 | 2.63 | 2.21 | 2.68 | 2.58 | 2.51 |
| Snorkeling | 3.49 | 3.56 | 3.76 | 3.96 | 3.85 | 4.00 |
| Recreational fishing | 3.65 | 3.64 | 3.29 | 3.49 | 2.92 | 3.37 |
| Global climate change | 2.70 | 3.05 | 2.36 | 2.80 | 2.23 | 2.81 |

Scale: 1 = extremely negative impact through 4 = neutral to 7 = extremely positive impact.

Source: Loomis et al. (2008 a,b,c)

| Table 6.13: Rating current ecological health of Florida Keys coral reefs | | | | | | |
|---|---|---|---|---|---|---|
| Mean Score | Recreational fishers | | Snorkelers | | Scuba divers | |
| | Residents | Visitors | Residents | Visitors | Residents | Visitors |
| Poor = 1 | 19.0% | 3.7% | 19.4% | 4.9% | 30.0% | 6.0% |
| Fair = 2 | 31.6% | 27.3% | 33.3% | 24.2% | 30.0% | 28.2% |
| Good = 3 | 35.4% | 46.9% | 41.6% | 42.5% | 31.7% | 38.9% |
| Very good = 4 | 15.7% | 20.1% | 5.6% | 26.1% | 6.6% | 24.1% |
| Excellent = 5 | 1.3% | 2.0% | 0.0% | 2.3% | 1.7% | 2.8% |
| Arithmetic mean | 2.46 | 2.89 | 2.33 | 2.97 | 2.20 | 2.89 |

Source: Loomis et al. (2008 a,b,c)

Asked whether the ecological health of the reefs had changed (Table 6.14), residents again were harsher in their judgment than visitors: the arithmetic mean was close to 2, "declining somewhat" (the average for the three groups was 2.08, but resident snorkelers and scuba divers experiencing the reef direct took an even less favorable view than resident recreational fishers). Visitors thought on average that the health trend was about halfway between "declining somewhat" and "staying the same" (average 2.55), with not much difference between the three groups.

| Table 6.14: Change in ecological health of Florida Keys coral reefs | | | | | | |
|---|---|---|---|---|---|---|
| Mean Score | Recreational fishers | | Snorkelers | | Scuba divers | |
| | Residents | Visitors | Residents | Visitors | Residents | Visitors |
| Declining substantially | 20.3% | 6.3% | 23.7% | 7.6% | 35.6% | 8.7% |
| Declining somewhat | 44.3% | 43.7% | 60.5% | 44.5% | 37.2% | 45.5% |
| Staying the same | 22.8% | 35.8% | 10.5% | 35.0% | 13.6% | 30.6% |
| Improving somewhat | 11.4% | 13.2% | 5.3% | 11.9% | 13.6% | 14.3% |
| Improving substantially | 1.3% | 1.0% | 0.0% | 1.0% | 0.0% | 1.0% |
| Arithmetic mean | 2.29 | 2.59 | 1.90 | 2.54 | 2.05 | 2.53 |

Source: Loomis et al. (2008 a,b,c)

## 6.4 Socioeconomic monitoring in the Florida Keys

The recreation and tourism part of the Socioeconomic Research and Monitoring Program for the Florida Keys is highly important in this future-orientated project. It was set up in the fiscal year 1998 to complement the Sanctuary's ecological monitoring program. A primary goal of the program is to detect and document resultant changes in sanctuary resource utilization patterns and their impact on market and nonmarket economic values of sanctuary resources. The problem of valuing these resources is discussed in Section 6.5.

The website, http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/, is headed sanctuary science. It has links to recreation and tourism, commercial fishing, marine zoning and reserves, knowledge, attitudes and perceptions of management strategies and regulations, and climate change – the last describing how the current project was modeled on an earlier study of the Great Barrier Reef (Hoegh-Guldberg and Hoegh-Guldberg 2004).

In the context of this section, the interest is in information that can be derived from changing variables or conditions, to evaluate possible futures for the Florida Keys for the scenario-building which follows in Chapter 7.

The backbone of the socioeconomic monitoring program is the surveys of visitors and residents in 1995-96 (Leeworthy and Wiley 1996a,b, 1997), and similar surveys for 2007-08 which became successively available for visitors from December 2009, when the initial results were presented (Leeworthy and Loomis 2009). Subsequently, Dr Leeworthy has made other essential results available as indicated below the individual tables in this section.

### 6.4.1 Visitors to the Florida Keys

The Florida Keys are visited for either recreation/leisure or other purposes. They were only given a questionnaire if visiting for the former purpose (which defines them as tourists). The survey methodology, however, made it possible to identify the number who traveled to the Keys for other purposes. Based on the findings in Table 6.15, visitors fall overwhelmingly into the leisure category; moreover, their ratio to total visitors increased from 83% in 1995-96 to 92% in 2008-09. The number of other visitors declined by half between the two surveys.

**Table 6.15: Total visitation, 1995-96 and 2007-08**

| | 1995-96 | 2007-08 | Change |
|---|---|---|---|
| **Person-trips/visits** | | | |
| Tourists | 2.54 | 3.01 | 18.5% |
| Other visitors | 0.52 | 0.26 | -50.0% |
| All visitors | 3.06 | 3.27 | 6.9% |
| **Person-days** | | | |
| Tourists | 13.30 | 12.82 | -3.6% |
| Other visitors | 2.97 | 1.12 | -62.3% |
| All visitors | 16.27 | 13.94 | -14.3% |
| **Average length of visit (days)** | | | |
| Tourists | 5.24 | 4.26 | -18.7% |
| Other visitors | 5.71 | 4.31 | -24.6% |
| All visitors | 5.32 | 4.26 | -19.8% |

Source: Leeworthy and Loomis (2009), Table C.1

Based on the 1995-96 survey, an estimated 2.54 million visits or "person-trips" took place during that year. It increased to 3.01 million in 2007-08. These figures are the basis for estimates made in subsequent tables of this section, though there was a change in the definition of recreation in 2007-08 to include "spa, health or wellness" activities. Using the 1995-96 definition, the increase in the number of visits for recreation purposes was reduced from 18.5% to 15%, and the decline in visits for other purposes was reduced from 50% to 34.6% (Leeworthy and Loomis 2009, p 4).

While noting this change, the basic story remains: more than nine of ten visitors to the Keys in 2007-08 came for recreation purposes, that is, as tourists. The remaining tables in this section concern these persons only.

**Table 6.16: Mode of access of visitors, percentage shares**

| Mode of access | Based on person-trips 1995-96 | Based on person-trips 2007-08 | Based on person-days 1995-96 | Based on person-days 2007-08 |
|---|---|---|---|---|
| Auto | 78.7% | 68.7% | 83.4% | 83.4% |
| Air | 8.7% | 5.2% | 14.2% | 9.5% |
| Cruise ship | 12.7% | 23.5% | 2.4% | 5.5% |
| Ferry | 0.0% | 2.6% | 0.0% | 1.6% |
| Total | 100% | 100% | 100% | 100% |

Source: Leeworthy and Loomis (2009), Table C.2

The other crucial variable in the surveys is the number of "person-days" visitors spend in the Keys. In contrast to the number of visits in the top panel of Table 6.15, the total number of person-days declined: from 13.3 million in 1995-96 to 12.8 million in 2007-08 for tourists, or by 3.6%. The average length of time tourists stayed declined from 5.24 days in 1995-96 to 4.26 days in 2007-08, or by almost 20%.

The main mode of access for visitors is by car, though the share based on person-trips fell from 78.7% to 68.7% between the two survey years (Table 6.16). The largest increase in share of person-trips was for cruise ships, from 12.7% to 23.5%. Another sea-based mode, by the newly introduced ferries to Key West from Miami (since discontinued), Fort Myers, and Marco Island accounted for 2.6% of person-trips in 2007-08. Finally, the share of person-trips by air fell from 8.7% in 1995-96, when Marathon Airport still received commercial flights, to 5.2% in 2007-08, when only Key West did so. The reduced share is not due to the cessation of commercial flights to Marathon: arrivals at Key West Airport were 18% lower in 2008 than in 1996 (Table 6.10).

Based on person-days, the automobile held its share at 83.4%, while there was a drop from 14.2% to 9.5% for air travel. Cruise ship passengers in Key West are day-travelers (by definition, they don't stay overnight on land). Their share of total person-days increased from 2.4% to 5.5% over the 12 years to 2007-08. Ferry passengers also stay for relatively short times in the Keys, showing a share of 1.6% of total person-days in 2007-08.

Tourists arriving by air tend to stay longer than other tourists (Table 6.17). While the average declined for both seasons, it remained at 8.6 days during the winter season and 6.4 days during the summer season. The average length of stay also

**Table 6.17: Average length of stay of visitors**

| Days per trip | 1995-96 | | 2007-08 | |
|---|---|---|---|---|
| Mode of access | Winter | Summer | Winter | Summer |
| Auto | 6.82 | 4.24 | 6.51 | 3.95 |
| Air | 9.04 | 7.65 | 8.63 | 6.40 |
| Cruise ship | 1.00 | 1.00 | 1.00 | 1.00 |
| Ferry | - | - | 2.50 | 2.97 |
| All modes | 6.03 | 4.17 | 4.94 | 3.51 |

Source: Leeworthy and Loomis (2009), Table C.8A declined for visitors arriving by automobile, to 6.5 days for the winter season and just under four days for the summer season during 2007-08. Ferry travelers stayed for shorter periods, and cruise ship passengers are defined as day travelers, as already noted.

The shortening of the average length of stay (“person-days”) is thus associated with two main factors: that both auto and air travelers stayed for shorter average periods in 2007-08 than in 1995-96, and because of the larger proportion of cruise ship passengers in 2007-08.

In addition to the changes in average length of visit and the pattern of access modes, the gender distribution has shifted towards a lower proportion of male respondents (from 72.8% to a still high 65.6%), and a higher average age (from 46.1 to 49.5 years). The age distribution is younger during the summer season when there are more families with children.

**Table 6.18: Statistically significant changes in visitor profiles, 1995-96 to 2007-08**

| | 1995-96 | | | 2007-08 | | |
|---|---|---|---|---|---|---|
| Socioeconomic/demographic indicator | Winter | Summer | Total | Winter | Summer | Total |
| Length of stay (days per trip) | 6.03 | 4.17 | 5.17 | 4.94 | 3.51 | 4.26 |
| Gender (male respondents/total) | 71.6% | 74.3% | 72.8% | 63.3% | 65.6% | 64.4% |
| Average age (years) | 49.55 | 42.16 | 46.13 | 54.26 | 44.23 | 49.53 |
| Median household income (2007-08 dollars) | na | na | $ 78,000 | na | na | $102,000 |

Source: Leeworthy and Loomis (2009), Table C.8

Most strikingly, the median household income in 2008 dollars increased from $78,000 to an estimated $102,000 (Table 6.18). That is, more than half (50.9%) of those respondents who answered the income question were from households earning more than $100,000 in 2007-08. The comparable proportion for 1995-96 is unknown, but the consumer price index grew by about 37% between the two surveys, so the next highest income group, $60000-$99,999, would have been equivalent to about $82,000-$137,000 at 2008 values.

That group accounted for 30.4% of those answering the income question in 1995-96, while those earning $100,000 and over in that year accounted for another 15.8%. The proportion of visitors earning $100,000 or more in 2008 values back in 1995-96 would be at most 35%, and probably closer to 30%. The increase between the two surveys is indeed remarkable.

Another characteristic showing statistically significant change was race/ethnicity. There were increases in all groups other than “White not Hispanic”, the largest being Hispanic growing from 4.8% to 5.8%, and Black, from 1.8% to 3.5%. The White group did show a statistically significant fall from 92.5% to 89.7% but the proportion remained numerically overwhelming.

Family composition and party size did not change significantly, but they revealed differences between the summer and winter seasons adding to the observations already shown in Table 6.18 for length of stay, and gender and age distributions. In 2007-08, the mean party size in the winter season was 2.40 persons, and in the summer season 3.17 (average 2.76), the average number of children was 0.12 in winter and 0.51 in summer (average 0.31), and the proportion of parties with no children 92.8% in winter and 71.9% in summer (average 82.8%). The summer season was demonstrably more family-orientated than the winter season in 2007-08, and also in 1995-96.

**Table 6.19: Home address of visitors to Florida Keys**

| Residential address | 1995-96 | | | 2007-08 | | | Statistically significant? |
|---|---|---|---|---|---|---|---|
| | Winter | Summer | Total | Winter | Summer | Total | |
| South Florida Metro | 8.8% | 27.0% | 17.2% | 9.6% | 20.7% | 14.9% | Yes |
| Rest of Florida | 7.6% | 18.9% | 12.8% | 9.1% | 14.8% | 11.7% | Yes |
| Rest of USA | 68.3% | 35.3% | 53.1% | 65.7% | 44.9% | 55.9% | Probably |
| Foreign country | 15.3% | 18.8% | 16.9% | 15.6% | 19.6% | 17.5% | No |

Source: Leeworthy and Loomis (2009), Table C.9.

The winter and summer seasons also show some substantial differences for origin of visitors (Table 6.19). Though the difference diminished between 1995-96 and 2007-08, visitors from the nearest neighbor, the South Florida Metropolitan Area of Miami-Dade, Broward and Palm Beach Counties remained strongly inclined to visit in the summer season. So, to a slightly lesser extent, did visitors from the rest of Florida. Together, Florida made up 18.7% of winter visitors and 35.5% of summer visitors in 2007-08 (26.6% for the year).

The rest of the United States was attracted mainly during the winter season, when it accounted for 65.7% of all visitors in 2007-08 (down from 68.3% in 1995-96). It is natural to expect the attraction from the northern United States (and Canada) to be particularly strong during winter, since what is called winter in Florida is still balmy in comparison. However, in the summer season the proportion of visitors from the rest of the US was 44.9% in 2007-08, which represented a large increase from 35.3% in 1995-96.

For 2007-08 as a whole, visitors from the rest of the nation represented 55.9% of total visitors, which is probably a significant increase from 53.1% in 1995-96. The changes in the winter and summer seasons almost certainly would be statistically significant, but they went in opposite directions thus tending to cancel each other out. (The rest-of-US component was derived as a residual from Leeworthy and Loomis 2009, p 13.)

The 2007-08 survey found a small increase (from 16.9% to 17.5%) in the proportion of foreign visitors. It was not statistically significant. Canada was the largest group, increasing its share from 4.8% to 6.2% (winter), from 1.1% to 2.8% (summer), and from 3.1% to 4.6% for the year. These changes were all statistically significant. The second largest foreign group was the United Kingdom, increasing its winter visitation from 2.8% to 3.6% but dropping back in the summer from 4.2% to 3.0%. Both these changes were statistically significant whereas the overall change, from 3.5% to 3.3%, was not, since the two seasonal components pulled in opposite directions.

### 6.4.2 Visitation patterns, overnight and day visitors

The subject matter under this heading is the extent to which people stay in the particular district of the Florida Keys where they are accommodated, or whether they travel widely across the Keys. There are connections from this to whether the particular tourists are overnight or day visitors, as described below.

The five districts identified in the 2007-08 survey correspond to the districts used by the Monroe County Tourist Development Council (TDC), and also to the five Chambers of

Commerce in Key Largo, Islamorada, Marathon, Lower Keys (Big Pine), and Key West. These districts also provided the geographic structure for the five scenario-planning workshops in 2008 (refer Appendices 1 and 2).

The 1995-96 survey combined Islamorada and Marathon, but the comparison in Table 6.20 compensates for the difference by eliminating visits to the two districts only. Thus, 12.5% of tourists visited Islamorada and 8.5% visited Marathon in 2007-08. The 21% total involved double counting of 1.5% of total visitors who visited the two districts only. They were eliminated to arrive at a comparison with 1995-96 (upper panel of Table 6.20).

**Table 6.20: Visitation by TDC district, 1995-96 and 2007-08**

| TDC District | Survey year | | Change | |
|---|---|---|---|---|
| | 1995-96 | 2007-08 | % points | Relative |
| **Visited district** | | | | |
| Key Largo | 35.9% | 26.9% | -9.0 | -25.0% |
| Islamorada | na | 12.5% | na | na |
| Marathon | na | 8.5% | na | na |
| Islamorada+Marathon | 27.4% | 19.5% | -7.9 | -28.9% |
| Lower Keys | 12.0% | 6.5% | -5.4 | -45.4% |
| Key West | 55.8% | 66.8% | 11.0 | 19.7% |
| **Visited one district only** | | | | |
| Key Largo only | 22.1% | 16.9% | -5.2 | -23.6% |
| Islamorada only | na | 5.4% | na | na |
| Marathon only | na | 3.7% | na | na |
| Islamorada+Marathon only | 14.2% | 9.7% | -4.5 | -31.7% |
| Lower Keys only | 4.3% | 1.6% | -2.7 | -62.2% |
| Key West only | 38.5% | 53.0% | 14.5 | 37.5% |
| **Visited two or more districts** | | | | |
| Including Key Largo | 13.8% | 10.0% | -3.7 | -27.2% |
| Including Islamorada | na | 7.1% | na | na |
| Including Marathon | na | 4.8% | na | na |
| Including Islamorada+Marathon | 13.2% | 9.8% | -3.4 | -25.9% |
| Including Lower Keys | 7.7% | 4.9% | -2.8 | -36.0% |
| Including Key West | 17.3% | 13.8% | -3.5 | -20.2% |

Source: Leeworthy and Loomis (2009), Table C.3

The upper panel of total visits counts any observation to any district. Someone visiting all four districts (in the 1995-96 definition before separating Islamorada and Marathon) is counted four times. The total number of observations adds to 131% of total visitors/tourists in 1995-96, falling to 120% for 2007-08. This indicates that tourists traveled less extensively within the Keys in the latter year.

The changes for each district are calculated in two different ways: by number of percentage points (yellow) and relative change in the distribution between 1995-96 and 2007-08 (light yellow). Both indicators show a solid shift towards Key West, away from the other districts, between the two survey years. The relative change in Key Largo was -25%, in Islamorada/Marathon -29%, and in the Lower Keys -45%. Key West shows a relative 20% gain, and a massive gain from 56% to 67% of the total observations.

The second panel shows tourists visiting only one district, which means that they are counted once only. Key West again stands out. As many as 53% of all tourists visited Key West only in 2007-08 compared to 38.5% in 1995-96, a relative gain of 37.5%. The next most popular sole destination, Key Largo, experienced a decline from 22% to 17% of all tourists (relative loss 24%), Islamorada/Marathon a decline from 14% to 10% (relative loss 32%), and Lower Keys a decline from 4.3% to 1.6% (relative loss 62%).

**Table 6.21: Overnight visitors' travel patterns**

| | 1995-96 | | | 2007-08 | | | Relative to total | |
|---|---|---|---|---|---|---|---|---|
| Thousand visits | Winter | Summer | Total | Winter | Summer | Total | 1995-96 | 2007-08 |
| Total overnight visitors | 1,070.8 | 948.5 | 2,019.3 | 1,033.0 | 921.0 | 1,954.0 | | |
| **Total districts visited** | | | | | | | | |
| Key Largo | 408.6 | 375.6 | 784.2 | 294.8 | 365.7 | 660.5 | 28.3% | 22.0% |
| Islamorada | | | | 180.5 | 148.5 | 329.0 | | 13.5% |
| Marathon | | | | 150.2 | 91.4 | 241.6 | | 11.2% |
| Islamorada+Marathon | 325.6 | 313.1 | 638.7 | *307.1* | *222.8* | *529.8* | 23.1% | *22.9%* |
| Lower Keys | 173.8 | 118.8 | 292.6 | 86.6 | 108.5 | 195.1 | 10.6% | 6.5% |
| Key West | 662.8 | 389.3 | 1,052.1 | 651.8 | 528.8 | 1,180.6 | 38.0% | 48.6% |
| Total districts visited | 1,570.8 | 1,196.8 | 2,767.6 | 1,340.3 | 1,225.8 | 2,566.0 | 100.0% | 100.0% |
| **Visited one district only** | | | | | | | | |
| Key Largo | 195.9 | 262.9 | 458.8 | 148.4 | 222.1 | 370.5 | 16.6% | 11.1% |
| Islamorada | | | | 73.1 | 54.5 | 127.6 | | 5.5% |
| Marathon | | | | 61.0 | 43.4 | 104.4 | | 4.6% |
| Islamorada+Marathon | 117.4 | 210.7 | 328.1 | 134.1 | 97.9 | 232.0 | 11.9% | 10.0% |
| Lower Keys | 46.5 | 60.8 | 107.3 | 23.6 | 24.9 | 48.5 | 3.9% | 1.8% |
| Key West | 372.5 | 250.0 | 622.5 | 434.3 | 332.5 | 766.8 | 22.5% | 32.4% |
| Total | 732.3 | 784.4 | 1,516.7 | 740.4 | 677.4 | 1,417.8 | 54.8% | 55.2% |
| **Visited two or more districts** | | | | | | | | |
| Key Largo | 212.7 | 112.7 | 325.4 | 146.4 | 143.6 | 290.0 | 11.8% | 10.9% |
| Islamorada | | | | 107.4 | 94.0 | 201.4 | | 8.0% |
| Marathon | | | | 89.2 | 48.0 | 137.2 | | 6.7% |
| Islamorada+Marathon | 208.2 | 102.4 | 310.6 | *173.0* | *124.9* | *297.8* | 11.2% | *12.9%* |
| Lower Keys | 127.3 | 58.0 | 185.3 | 63.0 | 83.6 | 146.6 | 6.7% | 4.7% |
| Key West | 290.3 | 139.3 | 429.6 | 217.5 | 196.3 | 413.8 | 15.5% | 16.2% |
| Total | 838.5 | 412.4 | 1,250.9 | 599.9 | 548.4 | 1,148.2 | 45.2% | 44.8% |

Note: Minor discrepancies due to rounding included in residual bottom panel. Islamorada+Marathon estimated from ratio of 19.5/21.0 in top panel of Table 6.20 (estimates are shown in italics).

Source: Special tables compiled by Bob Leeworthy for overnight visitors, May 2010.

The second panel adds to 79.1% of all tourists in 1995-96, and 81.2% in 2007-08. This means that the residual observations (bottom panel, which shows the top less the middle panel of Table 6.20) relate to those who visited more than one district, that is, 20.9% of tourists in 1995-96 and 18.8% in 2007-08. In 1995-96, the residual visits added to 52% of the number of tourists, or an average of 2.5 of the four identified districts visited. By 2007-08, the number of residual observations had fallen to 38.5% of tourists, so the number of districts visited per tourist was now just over two – a relative decline of almost 20% since 1995-96. All four identified districts in the bottom panel suffered declines, including Key West, as people traveled less within the Florida Keys during their visit.

The question is whether Key West's massive and increasing lead is mainly due to the fact that it receives the majority of day visitors as cruise ship passengers. Table 6.21 is similar to Table 6.20 showing the distribution of overnight visitors, with the added benefit of showing absolute numbers rather than percentage distributions.

The top line in Table 6.21 shows the total number of overnight visitors declining from 2.02 million in 1995-96 to 1.95 million in 2007-08 (-3.2%).

The top panel of Table 6.21 shows that the total number of districts visited by all tourists fell from 2.77 to 2.57 million (-7.3%).

According to the middle panel, 1.52 million overnight visitors visited one district only in 1995-96, falling to 1.42 million in 2007-08 (-6.5%). They represented 54.8% of total observations but 75.1% of total visitors in 1995-96, and 55.2% of total observations for 72.6% of total overnight visitors in 2007-08.

About 45% of overnight visitors visited more than one district in both years: about 502,600 persons in 1995-96 and 536,200 persons in 2007-08 (lower panel of Table 6.21). Between them they generated 1.25 million visits to districts in 1995-96 and 1.15 million in 2007-08

**Table 6.22: Overnight and day visitation by mode of access**

| Access mode | 1995-96 | | | | 2007-08 | | | |
|---|---|---|---|---|---|---|---|---|
| | Overnight | Day | Total | Day share | Overnight | Day | Total | Day share |
| **Person-trips (number of visitors - thousand)** | | | | | | | | |
| Auto | *1,808* | *189* | 1,997 | 9.5% | 1,750 | 318 | 2,068 | 15.4% |
| Air | *212* | *9* | 221 | 4.1% | 150 | 6 | 157 | 4.1% |
| Cruise ship | - | 323 | 323 | 100.0% | - | 707 | 707 | 100.0% |
| Ferry | - | - | - | - | 54 | 25 | 78 | 31.3% |
| Total | 2,020 | 521 | 2,540 | 20.5% | 1,954 | 1,056 | 3,010 | 35.1% |
| **Person-days - thousand** | | | | | | | | |
| Auto | *10,898* | *189* | 11,087 | 1.7% | 10,372 | 318 | 10,690 | 3.0% |
| Air | *1,879* | *9* | 1,888 | 0.5% | 1,211 | 6 | 1,218 | 0.5% |
| Cruise ship | - | 323 | 323 | 100.0% | - | 707 | 707 | 100.0% |
| Ferry | - | - | - | - | 181 | 25 | 205 | 12.0% |
| Total | 12,777 | 521 | 13,299 | 3.9% | 11,764 | 1,056 | 12,820 | 8.2% |

Note: Figures in italics are estimates (day trips in 1995-96 for auto, and Key West and Marathon Airports).

Sources: Leeworthy and Loomis (2009), Tables C.1 and C.2, plus Leeworthy Tables C.10, C.14, 4.1, and 4.2

(Islamorada and Marathon adjusted to count as one). The average per overnight visitor was close to the finding for all tourists in Table 6.20: 2.5 in 1995-96 and 2.1 in 2007-08.

This leaves the change in distribution by districts. The top panel shows that even without the cruise ship passengers Key West increased its share of total observations from 38% to 48.6%.

Key Largo lost share from 28.3% to 22%, Islamorada/Marathon held its share at 23%, and Lower Keys lost share from 10.6% to 6.5%.

Relating the observed numbers in the middle panel of Table 6.21 (visited one district only) to the top line of total overnight visitors, Key West increased its share from 30.8% to 39.2%, while other districts suffered losses: Key Largo from 22.7% to 19.0%, Islamorada and Marathon from 16.2% to 11.9%, and Lower Keys from 5.3% to 2.5%. These estimates can be compared with the observed shares in the middle panel of Table 6.20. For example, among total visitors, 38.5% visited Key West only in 1995-96, growing to 53% in 2007-08. Key West accordingly did not just benefit from the increased number of cruise ship passengers.

Table 6.22 suggests that the number of person-trips (visits) associated with day visitors grew mainly as a result of cruise ship passengers. They made up 20.5% of all visits in 1996-97 and 35.1% in 2007-08. Cruise ships accounted for 62% of all day visitors in terms of person-trips in 1995-96, growing moderately to 67% in 2007-08, but the share of day visitors also increased substantially for people arriving by auto: 9.5% in 1995-96 and 15.4% in 2007-08. This contrasted with the number of arrivals of overnight visitors driving to the Keys falling from 1.8 million in 1995-96 to 1.75 million in 2007-08.

In terms of person-days, we arrive at a less dramatic picture, because both auto and air gets weighted with the average number of days staying in the Florida Keys. Day visitors arriving by air is by any measure a small proportion of total arrivals by air, and in the case of automobiles increased from 1.7% to 3% of total person-days, not a dramatic figure. Even for cruise ships, 323,000 person-days in 1995-96 accounted for only 2.4% of total person-days, rising to 707,000 or 5.5% in 2007-08.

**Table 6.23: Activity participation rates and number of participants**

| | Participation rates | | | Thousand participants | | |
|---|---|---|---|---|---|---|
| Activity/activity group | 1995-96 | 2007-08 | Change[1] | 1995-96 | 2007-08 | Change |
| Visiting museums or historic areas | 33.0% | 41.3% | 25.4% | 837.2 | 1,242.7 | 48.4% |
| Cultural events (fairs, concerts, plays) | 7.4% | 9.0% | 21.4% | 188.0 | 270.0 | 43.6% |
| Beach use | 32.5% | 27.6% | -15.0% | 825.2 | 830.7 | 0.7% |
| Sightseeing and attractions | 55.3% | 45.0% | -18.5% | 1,403.6 | 1,354.5 | -3.5% |
| All diving | 31.3% | 23.7% | -24.1% | 794.2 | 713.5 | -10.2% |
| Boating | 49.1% | 35.0% | -28.7% | 1,246.2 | 1,096.5 | -12.0% |
| Viewing wildlife/nature | 28.6% | 19.9% | -30.5% | 726.8 | 598.2 | -17.7% |
| Fishing | 21.0% | 12.9% | -38.6% | 534.4 | 388.4 | -27.3% |
| Outdoor sports and games | 4.1% | 2.3% | -43.6% | 103.1 | 68.7 | -33.3% |
| Camping | 7.8% | 2.4% | -69.7% | 198.8 | 71.1 | -64.2% |
| Snorkeling | 28.3% | 21.8% | -23.0% | 720.0 | 656.6 | -8.8% |
| SCUBA diving | 8.1% | 4.9% | -39.3% | 204.6 | 147.0 | -28.2% |
| Any water-based activities | 65.7% | 53.0% | -19.3% | 1,673.8 | 1,594.9 | -4.7% |
| Any land-based actitivies | 78.5% | 78.7% | 0.3% | 1,994.6 | 2,368.1 | 18.7% |
| Only water-based activities | 18.9% | 11.0% | -41.6% | 480.2 | 308.9 | -35.7% |
| Only land-based actitivies | 31.2% | 35.1% | 12.3% | 793.5 | 1,107.7 | 39.6% |

[1] Relative change (assuming constant total number of participants in 1995-96 and 2007-08). Activities in top box sorted according to percentage change in participation rates.

Source: Leeworthy and Loomis (2009), Tables C.4 and C.5.

### 6.4.3 TOURIST ACTIVITIES

Visiting museums or historic areas emerged as the most strongly growing tourist activity in the Florida Keys between 1995-96 and 2007-08 (Table 6.23). The participation rate increased by 25% between the two years, and the number of participants nominating the activity grew from 837,000 to 1.24 million during the 12 years (48.4%).

Attending cultural events was the second-most strongly growing activity, but the actual number of participants was much lower.

Diving (both snorkeling and scuba), boating, viewing wildlife and nature, and fishing, all declined, whether measured as participation rates or number of participants. Overall, water-based activities declined in both participation rates and numbers, whereas land-based activities increased on both scores. Land-based activities continued to outnumber water-based activities, with 2.37 million compared with 1.59 million involved in 2007-08. A rapidly declining minority is involved in water-based activities only (309,000 in 2007-08) compared with a strongly growing number (1.1 million in 2007-08) participating in land-based activities only.

**Table 6.24: Annual number of days spent on each activity**

| Thousand days | 1995-96 | 2007-08 | Change |
|---|---|---|---|
| Snorkeling | 1,702.5 | 1,854.4 | 8.9% |
| SCUBA diving | 534.5 | 451.8 | -15.5% |
| All diving | 2,237.0 | 2,306.2 | 3.1% |
| Fishing | 1,949.8 | 1,312.1 | -32.7% |
| Personal watercraft use | 378.4 | 264.6 | -30.1% |
| Sailing | 217.7 | 162.6 | -25.3% |
| Other boating | 260.7 | 273.2 | 4.8% |
| Viewing nature and wildlife from land | 1,789.8 | 1,524.5 | -14.8% |
| Viewing nature and wildlife from water | 855.4 | 661.0 | -22.7% |
| All viewing nature and wildlife | 2,645.2 | 2,185.5 | -17.4% |
| All beach activities | 2,688.6 | 3,162.9 | 17.6% |
| Windsurfing or sailboarding | 24.4 | 17.8 | -27.0% |
| Swimming in outdoor pools | 2,489.2 | 2,379.3 | -4.4% |
| Visiting museums and historic sites | 1,695.3 | 2,592.6 | 52.9% |

Source: Table C.10 (received from Bob Leeworthy in May 2010)

Table 6.24 suggests that the number of days spent on diving increased marginally between 1995-96 and 2007-08 due to increased snorkeling (despite a declining number of participants), with scuba diving declining. Fishing declined by 33% in terms of time used, boating presented a mixed picture, and viewing nature and wildlife either on land or water were declining activities measured by time used. Beach activities increased, but the strongest growth remained visiting museums and historic sites.

### 6.4.4 ECONOMIC IMPACT OF TOURISM

At constant-value dollars, spending per person per trip declined by 2.7% between the two surveys, and by 3.5% per person-day. Spending per person per trip was higher during the winter than summer season, but both declined, marginally in winter and more strongly in summer. Daily spending per person declined by 14.3% during the winter season but increased by 12% during summer. Spending increased whether per person-trip or per person-day for people arriving by car or into Key West International Airport. Spending fell strongly (on land) for cruise ship passengers (Table 6.25).

**Table 6.25: Visitor spending in Monroe County**

| Dollars at 2008 values | Per person per trip | | | Per person per day | | |
|---|---|---|---|---|---|---|
| | 1995-96 | 2007-08 | Change | 1995-96 | 2007-08 | Change |
| Total | $ 623 | $ 606 | -2.7% | $ 149 | $ 144 | -3.5% |
| **By season** | | | | | | |
| Winter | $ 671 | $ 669 | -0.4% | $ 159 | $ 136 | -14.3% |
| Summer | $ 566 | $ 536 | -5.3% | $ 138 | $ 155 | 12.0% |
| **By mode of access** | | | | | | |
| Auto | $ 692 | $ 711 | 2.7% | $ 147 | $ 158 | 7.5% |
| Air - Key West | $ 1,652 | $ 1,716 | 3.9% | $ 201 | $ 258 | 28.4% |
| Cruise ship | $ 138 | $ 84 | -39.1% | $ 129 | $ 84 | -34.9% |
| Ferry | na | $ 301 | na | na | $ 115 | na |

Source: Leeworthy and Loomis (2009), Tables C.6 and C.6A.

The impact on the Monroe County economy was calculated in meticulous detail by Bob Leeworthy and includes not only the trip costs identified in the surveys but also the annual expenditure by people owning or leasing condominium and time share facilities (the dominant item), marina storage services, and recreational vehicle/trailer parks. The impact also includes estimated multiplier or "ripple" effects of the primary expenditure in Monroe County (Table 6.25). Total tourist spending in the County, after adjusting for inflation, increased by 22% over the 12-year period (Table 6.26). The economic impact or contribution to the Monroe County economy of this spending increased by 22.5% in terms of total sales or output, 40% of extra income to Monroe County residents, and 47% of additional jobs.

These findings are compatible with the changes to the Monroe County economy observed in Table 6.4, which showed an upwards trend in personal income adjusted for inflation, and Table 6.6 showing structural change: declining retail and hospitality service employment and a strong increase in real estate employment suggesting much increased activity in that sector.

**Table 6.26: Total impact of visitor spending on Monroe County economy**

| Million dollars at 2008 values | Including multiplier effects | | | Proportion of economy | |
|---|---|---|---|---|---|
| | 1995-96 | 2007-08 | Change | 1995-96 | 2007-08 |
| Total spending | 1,630 | 1,990 | 22.1% | | |
| Total sales/output | 1,820 | 2,230 | 22.5% | 60.5% | 59.9% |
| Total income | 693 | 970 | 40.0% | 45.0% | 46.9% |
| Total employment (thousand full-time and part-time jobs | 21.8 | 32.0 | 46.8% | 46.5% | 57.0% |

Source: Leeworthy and Loomis (2009), Table C.7

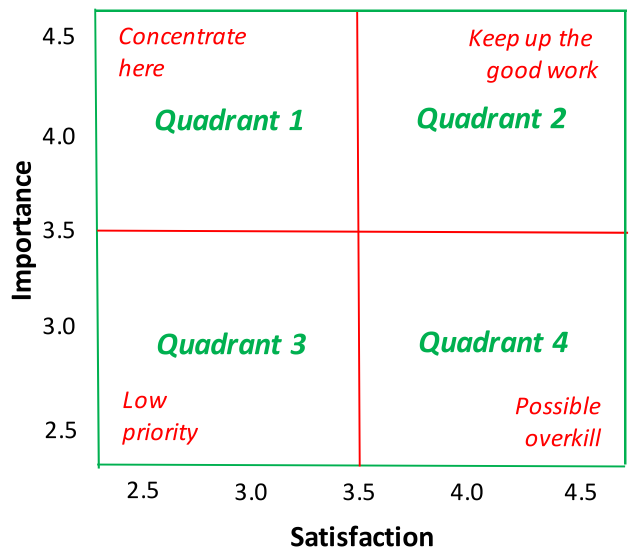
The total sales or output generated by tourism was about 60% of the total Monroe County economy in both 1995-96 and 2007-08. It represented 45-47% of the total income of the County, and 46.5% of the total number of full-time and part-time jobs in 1995-96, rising to 57% in 2007-08 (Table 6.26).

### 6.4.5 IMPORTANCE AND SATISFACTION RATINGS

One of the major contributions of the surveys are the ratings that visitors (and residents) put on a range of resources, facilities and services, using an approach originally developed for marketing purposes but widely adopted as a planning tool. The ratings have two dimensions for each item: importance to the respondents, and how satisfied they are. Both use five-point scales with the highest importance and satisfaction scores rated highest.

Combining the average importance and satisfaction ratings for a total sample or its subgroups results in a matrix with importance and satisfaction as its two dimensions (Figure 6.4). The matrix is divided into four quadrants combining the ratings. An average rating of 3.5 is used as a dividing mark between what is rated important and not important, and what is rated satisfactory and less satisfactory.

**Figure 6.4: Importance-satisfaction matrix**




Source: From Leeworthy et al. 2004

While this provides an important guide to priority setting, the tool could be further developed to target specific groups, rather than concentrating on total groups of surveyed residents of or visitors to the Florida Keys. It is of course a good democratic principle to ask everyone, and an important criterion in its own right. But it would also be interesting to analyze these combined ratings for selected groups, say, of opinion leaders or other people potentially capable of influencing political decisions directly. This could be done separately, outside the framework of major surveys.

Visitors and residents were asked in the surveys how important each of 25 resources, facilities and services were to them, using the scale from "unimportant" (1) to "extremely important" (5). The satisfaction scale runs from "very dissatisfied/terrible" (1) to "very satisfied/delighted" (5). The dividing mark on the importance scale of the matrix falls between "important" (3) and "very important" (4), and for satisfaction between "neutral" (3) and "somewhat satisfied" (4). Table 6.27 compares the averages for the two surveys, and which quadrant of Figure 6.4 they would fit into. Quadrants 1 and 2 identify the items rated above 3.5 on importance, with Quadrant 1 indicating which ones are below a satisfaction rating of 3.5. Table 6.27 also shows any statistically significant changes in ratings between 1995-96 and 2007-08, as calculated by Dr Leeworthy for the source tables.

There are four groups of items in Table 6.27, each sorted according to its importance in 2007-08. Of seven natural resource items, five were rated above the 3.5 mark for importance, with the averages for two items, quality of beaches and clear water, above 4 (very important). The least important item was opportunity to catch fish and other sea life, where the importance rating fell significantly since 1995-96. The rank order, and general magnitude of the averages, was otherwise similar between the survey years.

The satisfaction ratings for natural resources were above the 3.5 mark, except for opportunity to see large wildlife, and quality of beaches which was a borderline case. Both are in Quadrant 1 (high priority) in the source tables. One item, clear water, was rated significantly more satisfactory in 2007-08 than in 1995-96. Opportunity to catch fish and other sea life was the only item among the natural resources to fall into Quadrant 4 (ironically, for this particular activity, called "possible overkill").

The second group of items consists of six natural resource facilities. The average importance rating for parks and specially protected areas exceeded 4 (very important), and it also enjoyed a significant increase in satisfaction ratings. It falls into Quadrant 2 ("keep up the good work"). The second-most important item was designated swimming and beach areas, for which the rated importance increased significantly over the period. Both this and the third item, shoreline access, were considered relatively unsatisfactory, putting them in the high-priority Quadrant 1.

There was a significant decline in the rated importance of the three remaining items: mooring buoys near coral reefs, marine facilities, and boat ramps (though the rating remained above 3 for mooring buoys). There was relative satisfaction with all three items, and all fit Quadrant 4 (possible overkill).

Other facilities are installed to improve the comfort of tourists (and local citizens), such as public restrooms, the condition and cleanliness of streets, sidewalks and bike paths, signs and mile markers, uncrowded conditions, parking, and public transport. They were generally regarded as important, some significantly more so in 2007-08 than in 1995-96. They also received relatively high and often rising satisfaction ratings, and generally fit into Quadrant 2 ("keep up the good work"). The exceptions were public restrooms, regarded as very important with an average of 4.05 but relatively unsatisfactory despite a significant increase in the average satisfaction rating in 2007-08 (Quadrant 1), and parking and public transport being rated relatively unimportant as well as relatively unsatisfactory (Quadrant 3).

This leaves the odd item among "other facilities", historic preservation. This was not only considered highly and increasingly important but also received the highest satisfaction rating of all the items in Table 6.27 (4.05). Both ratings for historic preservation improved significantly between 1995-96 and 2007-08.

Three services include the highest importance ratings of all items in the opinion of tourists. They are customer service and friendliness of people, and value for the price. Both showed significantly increasing satisfaction ratings of above 4.2 in 2007-08. Their satisfaction ratings also increased significantly though remaining below 3.5 for value for the price (Quadrant 1).

**Table 6.27: Average importance and satisfaction ratings by tourist visitors**

| **Statistically significant change between surveys shown in bold italic color** | Importance ratings | | Satisfaction ratings | | Quadrant |
|---|---|---|---|---|---|
| | 1995-96 | 2007-08 | 1995-96 | 2007-08 | 2007-08 |
| **Natural Resources** | | | | | |
| Quality of beaches | 4.17 | 4.21 | 3.45 | 3.51 | ***1*** |
| Clear Water (high visibility) | 4.07 | 4.05 | ***3.82*** | ***3.96*** | ***2*** |
| Amount of living coral on reefs | 3.84 | 3.93 | 3.73 | 3.75 | ***2*** |
| Many different kinds of fish and sea life to view | 3.77 | 3.84 | 3.77 | 3.81 | ***2*** |
| Opportunity to view large wildlife (manatees, whales, dolphins, sea turtles) | 3.62 | 3.72 | 3.34 | 3.40 | ***1*** |
| Large numbers of fish | 3.50 | 3.46 | 3.52 | 3.56 | 3 |
| Many different kinds of fish and sea life to catch | ***2.88*** | ***2.69*** | 3.59 | 3.67 | 4 |
| **Natural Resource Facilities** | | | | | |
| Parks and specially protected areas | 3.93 | 4.02 | ***3.75*** | ***3.85*** | ***2*** |
| Designated swimming/beach areas | ***3.72*** | ***3.90*** | 3.38 | 3.43 | ***1*** |
| Shoreline access | 3.82 | 3.88 | 3.35 | 3.42 | ***1*** |
| Mooring buoys near coral reefs | ***3.35*** | ***3.16*** | 3.83 | 3.83 | 4 |
| Marina facilities | ***2.67*** | ***2.45*** | 3.71 | 3.79 | 4 |
| Boat ramps/launching facilities | ***2.56*** | ***2.35*** | 3.61 | 3.67 | 4 |
| **Other Facilities** | | | | | |
| Availability of public restrooms | ***3.82*** | ***4.05*** | ***3.30*** | ***3.40*** | ***1*** |
| Cleanliness of streets and sidewalks | ***3.79*** | ***3.91*** | 3.66 | 3.69 | ***2*** |
| Historic preservation (historic landmarks, etc) | ***3.72*** | ***3.86*** | ***3.88*** | ***4.05*** | ***2*** |
| Directional signs, street signs, mile markers | 3.72 | 3.67 | 3.64 | 3.72 | ***2*** |
| Conditions of roads and streets | 3.64 | 3.66 | 3.62 | 3.65 | ***2*** |
| Condition of bike paths and sidewalks | 3.51 | 3.59 | 3.64 | 3.67 | ***2*** |
| Uncrowded conditions | 3.52 | 3.58 | ***3.43*** | ***3.60*** | ***2*** |
| Parking | ***3.29*** | ***3.42*** | 3.34 | 3.27 | 3 |
| Public transportation | 2.27 | 2.39 | 3.35 | 3.49 | 3 |
| **Services** | | | | | |
| Customer service and friendliness of people | ***4.14*** | ***4.29*** | ***3.91*** | ***3.99*** | ***2*** |
| Value for the price | ***4.12*** | ***4.25*** | ***3.28*** | ***3.44*** | ***1*** |
| Maps, brochures, and other tourist information | 3.39 | 3.49 | ***3.85*** | ***3.96*** | 4 |
| **All Items** | 3.55 | 3.59 | 3.59 | 3.66 | |

Mean scores: Scale from 1 to 5 with 5 meaning extremely important/extremely satisfactory.
Statistical significance at 95% confidence level.

Source: Leeworthy Tables C.11, C.12 and C.13 supplied in May 2010.

Summing up, this project is primarily concerned with natural resources and associated facilities, but if the Keys are to preserve a healthy tourist industry, we must also recognize the importance of the tourism infrastructure listed under other facilities in Table 6.27. This includes both the provision of a comfortable and attractive human-made environment, and the preservation of the historic heritage in Key West and elsewhere.

Among the natural resources, it would have been reassuring to see an increase in the importance ratings for amount of living coral and for the biodiversity of the reef, but there was no improvement in this respect over the 12 years between the surveys. Among the natural resource facilities, the high rating of parks and specially protected areas was a positive sign, but the drop in the perceived importance of mooring buoys coupled with a high satisfaction rating (suggesting a degree of complacency, or a loss of knowledge as activity patterns change?) was a little disturbing. It seems to be part of the general change from sea-based to land-based activities identified in Section 6.4.3.

### 6.4.6 Resident surveys

The 2007-08 survey of residents, which was carried out in parallel with the visitor survey, was not yet available when this report was completed. The most important part of the resident survey from our point of view is likely to be the importance and satisfaction ratings and the extent to which these differ from those of the visitors.

It is more than likely that residents will rate key features more highly on importance and will be less satisfied with the current state of affairs. This was the general outcome of the UMASS Amherst studies reported in Section 6.3.3 (Loomis et al. 2008a,b,c) – more pronounced for snorkelers and scuba divers than for recreational fishers but apparent for all three.

**Table 6.28: Comparison of visitors' and resident's mean importance/satisfaction scores, 1995-96**

| All criteria where residents rated importance at 4 or more | Residents | | Visitors | | R - V | |
|---|---|---|---|---|---|---|
| | I | S | I | S | I | S |
| Clear Water (high visibility) | 4.40 | 3.50 | 4.21 | 3.81 | 0.19 | - 0.31 |
| Amount of living coral on reefs | 4.47 | 3.23 | 3.96 | 3.75 | 0.51 | - 0.52 |
| Many different kinds of fish and sea life | 4.22 | 3.49 | 3.94 | 3.83 | 0.28 | - 0.34 |
| Quality of beaches | 4.26 | 3.00 | 4.13 | 3.38 | 0.13 | - 0.38 |
| Parks and specially protected areas | 4.06 | 3.51 | 3.92 | 3.38 | 0.14 | 0.13 |
| Mooring buoys near coral reefs | 4.31 | 3.63 | 3.66 | 3.88 | 0.65 | - 0.25 |
| Service and friendliness of people | 4.21 | 3.46 | 4.13 | 3.87 | 0.08 | - 0.41 |
| Value for the price | 4.14 | 2.84 | 4.17 | 3.31 | - 0.03 | - 0.47 |

Source: Leeworthy and Wiley (1996,a,b).

It was also the finding of the 1995-96 surveys. Table 6.28 shows average importance and satisfaction ratings for residents and visitors, and the difference between the two. The comparison is limited to the eight items considered most important by residents. The difference between importance ratings for residents and visitors was highest for amount of living coral (which residents rated almost halfway between very important and extremely important with an average score of 4.47), and mooring buoys.

Satisfaction ratings were generally higher among visitors (with the exception of parks and specially protected areas) with the largest difference for amount of living coral on reefs. The coral indicator is particularly striking in demonstrating a difference between residents' and visitors' perceptions. It will be interesting to find out from the 2007-08 resident survey, when ready, whether their importance ratings have remained intact since 1995-96.

### 6.4.7 MAIN CHANGES OBSERVED IN THE SURVEYS

- There has been a declining trend in the average number of days people visit the Florida Keys as tourists, from 5.3 days in 1995-96 to 4.3 days in 2007-08. This was not only due to an increase in the number of day visitors (cruise ship passengers in Key West), but also to a decline in the average stay of people arriving by auto and air.
- So, despite an increase in the number of person-trips (visits) from 2.5 million in 1995-96 to 3 million in 2007-08, the total number of person-days declined from 13.3 million to 12.8 million.
- As well as day travelers visiting only one district (increasingly representing cruise ship passengers), overnight visitors were also less mobile in 2007-08 than in 1996-97. This is probably partly associated with a decline in sea-based activities including diving and recreational fishing, while land-based activities such as visiting museums and historic areas have increased strongly. This all favors Key West over Key Largo and other districts. With less incentive to engage in sea-based activities, however, it is not surprising that the average length of visits has fallen.
- Spending by visitors per person-day in constant 2008 dollars declined slightly from $149 in 1997-98 to $144 in 2007-08. However, total sales/output including multiplier effects increased by an estimated 22.5% between the two survey years, to $2.26 billion, representing 60% of the total Monroe County economy. The main reason was a strong increase in the number of tourists owning or leasing their own condominiums or time-share facilities, a sign of the structural change that has become evident in the Keys.
- Importance and satisfaction ratings by tourists are increasingly associated with infrastructure facilities for tourists, while coral reef health and biodiversity are not gaining importance. However, local residents take a stronger view on reef health than tourists, and are less satisfied with the state of coral reef health.

## 6.5 VALUING ECOSYSTEMS

This section starts with an overview of the links between the environment and the economy and the importance of extending the analysis to nonmarket values to capture these links better. Section 6.5.2 then demonstrates the difficulty of doing this in practice, referring to a study carried out on the Great Barrier Reef in Australia in 2009. Section 6.5.3 describes the valuable work for the Florida Keys extending over many years within NOAA's National Ocean Service. Section 6.5.4 proposes that the methodologies involved in valuing these ecosystems can be applied, with important modifications, to conditions of rapid climate change.

### 6.5.1 ENVIRONMENTAL QUALITY AND THE ECONOMY

We noted at the beginning of Section 6.4 that a primary goal of the Florida Keys Socioeconomic Research and Monitoring Program is to document changes in sanctuary resource utilization patterns and their impact on the economic values of sanctuary resources. In this context, linking the economy to the environment involves estimating the market and nonmarket economic values of recreation/tourist use of the Florida Keys ecosystem, demonstrating how these ecosystem values form an integral component of the economy when formulating sustainable development objectives and policies, and fostering cooperative management processes (Leeworthy and Bowker 1997, p ii).

Market economic values (sales/output, income, employment) are not good leading indicators of the long-term health of natural resources, because these values can increase in the short term by exploiting natural capital. The same applies to nonmarket economic values (consumer surplus) which can continue to increase for a while for similar reasons.

The level of sustainable use is a function of technology, individual behavior patterns, and institutions. Economic opportunities can be expanded by investments in technologies, behavioral changes, and institutional change that alter the relationships between environmental quality and use.

Environmental indicators can be better leading indicators of the long-term health of the natural resource-dependent economy (Leeworthy and Bowker 1997, p 2).

### 6.5.2 Total Economic Value approach to reef valuation

In Australia, the Great Barrier Reef Foundation in 2009 commissioned a study of the cost of total permanent bleaching of the GBR (Oxford Economics 2009). The report correctly states that using a Total Economic Value (TEV) approach is a broader concept than market-based valuation within a conceptual national accounting framework. The latter, especially in the conventional manner in which it is currently practiced, only identifies direct market-based uses. The TEV is the sum of what is termed producer surplus (profit) and consumer surplus (how much users and non-users are *willing to pay* to *visit* and *preserve* the reef).

This provides a framework for going past the purely market-based economic approach. Furthermore, since the reef is a long-lived natural resource, the benefits stretch into the future using a present-value approach derived via the use of a social discount rate. This, according to Oxford Economics, fits in with the emergence of climate change and its effects, which has "focused policymakers' minds on the long term effects of natural resource degradation on the broader economy as well." (p 16)

TEV consists of *use and non-use values*. *Direct market-based uses* of the GBR can be measured for tourism and fishing and any other industry, provided the appropriate data have been assembled. The focus here is on operating surplus or profit (*producer surplus*). However, use values also includes estimating how much more consumers would be willing to pay to experience the reef, giving rise to a *consumer surplus*.

*Indirect use values* need to be estimated from elsewhere. In the GBR report, they consist of "ecosystem services" protecting adjacent coastal areas from storms.

There are three main types of *non-use values*, which are not easy to distinguish in practice, and not even in concept judging from the descriptions below. The descriptions have been augmented with references from Bob Leeworthy's presentation to the FRRP Reef Resilience Conference in Key Largo in April 2008 on the economics of coral reef ecosystems.

*Option values*, according to the GBR report, are attached to potential future gains, for example new substances which point toward prospects for medical/pharmaceutical benefits that have not yet been identified. Leeworthy (2008) defines option values as current non-users' willingness to pay to ensure a resource is protected or restored to a certain condition so they might use it in the future – a kind of insurance policy. He calls the value we might obtain from future discoveries like medicinal properties of the corals a *quasi-option value*, like scientific value and educational value.

A *bequest value* is the value which members of the current generation place on preserving the GBR for the benefit of future generations. Leeworthy (2008) refers to the bequest value as the willingness to pay for future generations to have the opportunity to experience the resource in a certain condition or preserving its *existence value*, being willing to pay to simply know that a resource will be protected or restored to a certain condition. Existence values, as their name implies, are attached to the existence of the GBR, whether or not the person who makes the valuation ever visits it.

Figure 6.5 shows the connection between a current average price or cost of visiting the reef and the number of tourists paying this price. The supply curve describes the minimum price producers are willing to offer for reef visits, and the demand curve the maximum price consumers are willing to pay. The consumer and producer surpluses are indicated by the colored areas of Figure 6.5.

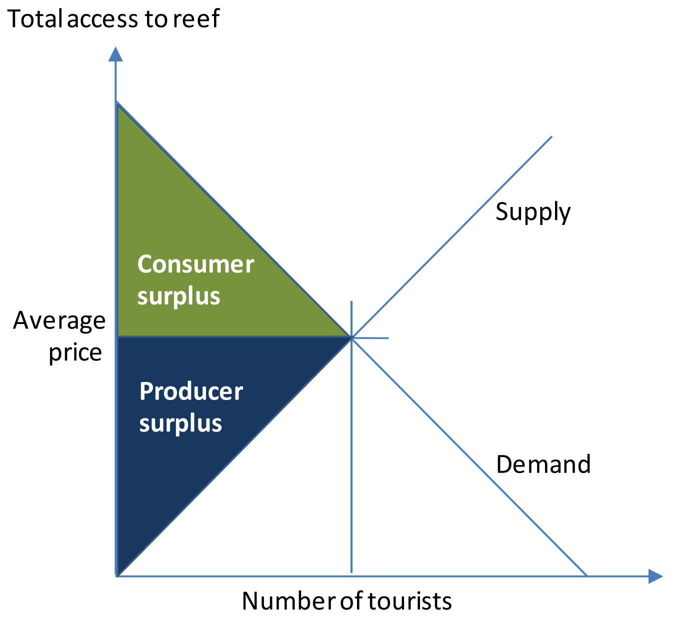



*Figure 6.5: Producer and consumer surpluses for tourism. The producer surplus (roughly equal to profits) is the difference between the price received by suppliers (the average price line) and the minimum price at which they would have been willing to sell commodities (in this case "reef visits") – i.e. the supply line. This represents the benefit to industry from the fact the GBR exists, and is captured by the blue area between the price line and the supply curve. The consumer surplus represents the difference between what consumers pay and the maximum price they would be willing to pay, in this case for a reef visit (the demand curve). It is represented by the olive green area between the price line and the demand curve. Source: Oxford Economics (2009), pp 18-19.*

The TEV approach in the Oxford Economics report involved holding all variables constant in real terms through the 100 years, including the current value of tourism, industry profits, and non-use values. Bleaching was assumed to be total from 2009 through the projected period to 2108. The present value of the GBR was an estimated $51.4 billion, and the present value cost of total bleaching $37.7 billion. The remaining value with a bleached reef was $13.7 billion. The Australian dollars shown here averaged 79 US cents in the base year of 2009. The estimates were based on a "preferred" discount rate of 2.65%, streamed over 100 years. The

Oxford Economics reports adds that the direct loss from a totally bleached GBR is equivalent to an annual $1.08 billion through the century.

The components of the TEV demonstrate the difficulties of obtaining a reliable database:

- *Tourism consumer surplus from reef-motivated visits to coral sites*: Present value $16.6 billion, present value cost of total bleaching $16.6 billion. All lost (excluding tourism to North and Central Queensland which was not attracted by the reef and therefore not part of the model). It was estimated from a range of studies that at least 50% of overnight visitors, and all domestic day visitors, who visited the coral sites would have not have done so if the GBR sites had suffered (p 23 et seq.). The tourism value was assessed by the travel-cost method using data from official tourism surveys.
- *Tourism producer surplus (profit) from reef-motivated visits to coral sites*: Present value $3.6 billion, all lost. This appears to be based on a fair empirical database.
- Recreational fishing consumer surplus from assessed value in the GBR Marine Park: present value $2.5 billion, none lost. "Recreational fishers appear to be largely motivated by "the experience not the catch"; it is uncertain if values would be materially impacted by bleaching." (p 23)
- *Recreational fishing producer surplus* (profit) from assessed value of regional fishing supplies: present value $0.3 billion, none lost. This covers supplies to recreational fishers and therefore reflects the assertion that the present value of recreational fishing would not be affected.
- *Commercial fishing producer surplus* (profit) from assessed value of commercial fishing within the GBR Marine Park: present value $1.4billion, cost $0.4 billion. This is based on what was seen as the most conservative loss estimate, which happened to be Hoegh-Guldberg and Hoegh-Guldberg (2004), that 30-36% of catches would be lost to bleaching. However, this estimate only covered the period up to 2020, with further losses to come, whereas the model used by Oxford Economics covers 100 years.
- *Indirect use value from assessed value of GBR as a physical barrier*: present value $10.0 billion, none lost. "Bleaching of the GBR may result in the eventual loss of some of this protection function. However, this is likely to be a long term process and no immediate impact has been estimated for this report." (p 42) "Further, from a practical point of view, even the effects of a relatively rapid (i.e. 30-50 years) reef destruction following bleaching would be considerably reduced by discounting." (p 46) See comments below.
- *National non-use value* from assessed value of coral sites and interrelated ecosystems. Present value $15.2 billion, all lost. The estimate was based on a comprehensive but dated study from 1987 and a 2005 project that covered only the Fitzroy Basis in the extreme south, where Brisbane households were asked how much they would be willing to pay for changes to the water quality of the Fitzroy estuary which is connected to and has a direct impact on the GBR lagoon (p 49).
- *International non-use value* from assessed value of coral sites and interrelated ecosystems. Present value $1.9 billion, all lost. This was based on a study of rainforests in the absence of data on coral reefs. The Oxford Economics authors note that GBR is

world heritage and a global resource, "On *a priori* grounds there must .. be a positive global [willingness to pay] for preserving the GBR as a part of the global ecosystem (i.e. as a "global public good.")." (p 53) But it is admitted in the report that the area is not well researched.

The competence of the Oxford Economics team is not an issue here, but clearly the lack of good data makes this type of analysis very difficult, and causes the results to be based on controversial assumptions. The estimated producer and consumer surpluses for tourism are probably the most solid. Further comments follow on other components:

- The evidence presented for recreational fishers in the report (p 33) suggests that some are concerned with whether or not they have a catch, which means that there might be an impact on the present value in the absence of a living reef. We add from the evidence of the Florida Keys surveys that the number of recreational fishers there has been declining, along with the coral cover diminishing. This suggests that the present value of recreational fishing would be lower, probably much lower, in a totally bleached GBR.
- To assume that commercial fishing would be reduced by only 30% if the reef dies is also based on questionable assumptions. In a study with a 100-year time frame it does not appear to make sense to measure the impact of the bleaching from a short period. Again, the evidence from Florida shows that the number of commercial fishers has dropped substantially along with the catch.
- To assume that the reef will continue to provide full protection to the Queensland coast appears to be overly optimistic, especially if ocean acidification and the likelihood of more violent storms are added as factors – something not assumed in the Oxford Economics report which does not mention acidification though it does cite examples of the reef being protected from cyclones in the past. A report commissioned by the Australian Garnaut Climate Change Review (Hoegh-Guldberg and Hoegh-Guldberg 2008, p 12) states:

  "If atmospheric $CO_2$ increases beyond 450 ppm, large-scale changes to coral reefs would be inevitable. Under these conditions, reef-building corals would be unable to keep pace with the rate of physical and biological erosion, and coral reefs would slowly shift towards non-carbonate reef ecosystems. .. As a result, the three-dimensional structure of coral reefs would slowly crumble and disappear. Depending on the influence of other factors such as the intensity of storms, this process may happen at either slow or rapid rates. It is significant to note that this has happened relatively quickly (over an estimated 30 to 50 years) on some inshore Great Barrier Reef sites. .. Loss of the calcium carbonate framework would also have implications for the protection provided by coral reefs to other ecosystems (e.g. mangroves and sea grasses) and human infrastructure, .. ."

  The principal author of the statement has not changed his opinion (Ove Hoegh-Guldberg, personal communication, May 2010).

  The assertion by the Oxford Economics authors that the chosen social discount rate would greatly diminish the weight of future years in the calculation of present values, raises questions about why in that case a 100-year period was chosen for the analysis, and whether the social discount rate should be lower, given that the rationale of the project was provided by the potential impact of climate change, which is referred to in numerous contexts in the report. See further Section 6.5.4.

### 6.5.3 The Florida Keys context

Designating a National Marine Sanctuary implies that the area and its resources are unique. "The stewardship of these sanctuaries are of national importance, yet involves a broad range of local concerns that affect the valuation process." (Wiley 2003, p 1) It was described in Section 4.3 how sanctuary resource management involves multiple overlapping jurisdictions including national, state and local government instrumentalities, as well as other stakeholder groups across a wide geographic range.

"The ways in which these various stakeholders value the resources are as disparate as their reasons for participating in their management. However, the most difficult stakeholder group's value to take into consideration is the US population as a whole. As a national resource, every citizen holds a claim to ownership of sanctuary resources. However, most of the attention is often paid to local stakeholders who use the resource directly." (Wiley 2003, p 1)

The chief economist of NOAA's Office of National Marine Sanctuaries, Bob Leeworthy, leads the effort to introduce nonmarket values into the economic analysis of the tourist and recreation activities in the Florida Keys, and elsewhere. The theoretical approach is similar to that taken in the Oxford Economics study of the Great Barrier Reef (effectively using a TEV or Total Economic Value model), but the insights of two decades or more of research add significantly to the approach due to a closer association with local issues of environmental quality and superior long-term general knowledge of the study area. Even so, Leeworthy (2008) notes:

"We have not estimated these [passive economic use] values for coral reefs anywhere in the world. However, we are currently doing this for Hawaii's coral reef ecosystem. In the Tortugas Ecological Reserve, we used a "policy analysis" employing conservative lower bound estimates of what these values might be, *and they exceeded all direct use values.*" (Italics added.)

Sustainable development depends on maintaining or increasing the natural capital stock of the area. Natural capital stock is represented by the quality of the environment and the abundance and diversity of the natural resources of the area. In the long run, market and nonmarket economic values will decline if environmental quality declines (Leeworthy and Bowker 1997).

*Asset value* is defined as the amount someone would be willing to pay today if they could own the reef resources and charge a price for their use. "It is like the value of a house or a car in which the asset has a certain life and it yields a stream of services over the life of the asset. But at any point in time there is a price someone would be willing to pay to own it." (Leeworthy 2008).

This is a central concept because it is associated with the purpose of the valuation. The approach up to this point has been to determine the asset value of the reefs for recreational use, using the following conservative lower-bound assumptions:

➢ The reefs have an indefinite life (perpetuity)

➢ Future annual reef use is constant, since we are unable to forecast very far into the future

➢ The future annual user value per unit of use is also constant in view of our inability to estimate people's preferences far into the future

➢ A real discount rate of 3% is used to convert future dollars to current dollars.

As discussed in Section 6.5.2, there are two categories of nonmarket values. In NOAA's understanding of economic welfare theory, the categories are the consumer surplus and a special sub-category of producer surplus, economic rent, which is relevant in the context of economic efficiency. Economic rent is the return on investment above "normal" returns on investment. In an open competitive environment, economic rents won't exist for long as new entrants will be attracted by the relatively high returns on investment. But there are time lags and other dynamics that delay the movement toward an equilibrium, and the higher return on investment can also persist when governments pass regulations that limit entry, for instance by prohibiting further draining of wetlands to build or expand marinas.

"Nonmarket user values for visits to the Florida Keys/Key West are determined, in part, by environmental quality. Increases in environmental quality would increase the demand for recreation/tourism." (Leeworthy and Wiley 1997, p 9) This would result in an upward shift in the demand curve and a resulting increase in both use value and consumer surplus (nonmarket economic use value). Figure 6.6 illustrates this effect, but we have noted in the description below the graph that the demand (up from $Q_1$ to $Q_2$ as shown) would eventually shift downward if environmental quality deteriorated.

The consumer surplus is what consumers receive from the consumption of a good or service over and above what they hope to pay for it. Since no one owns the reef resource, the estimated consumer surplus is itself the annual direct economic use value of the reef resource.

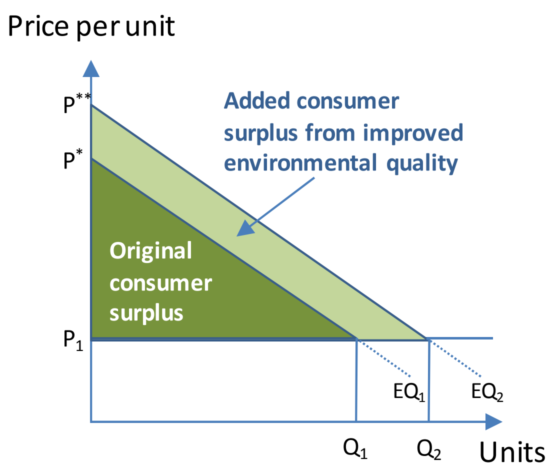



*Figure 6.6: Environmental quality and consumer surplus (nonmarket consumer value). The two sloping lines represent environmental quality, $EQ_1$ showing the original and $EQ_2$ following improved environmental quality. The change in quantity at a given price, $P_1$, is positive but might equally plausibly be negative, thus reducing the consumer surplus. Source: Leeworthy and Wiley (1997. p 9).*

Leeworthy and Wiley observed (1997, p 23) that although they explained the definitions of all major types of nonmarket economic values, they could only estimate the tourism and recreation uses of the natural resources of the Keys – then using the travel cost method but now apparently favoring the contingent valuation technique to identify people's willingness to pay, and willingness to accept a change. Also there were no attempts then to estimate the economic rents to producers (producer surplus) or the "passive use" values – bound to be important components as suggested by the Tortugas "policy analysis."

Nonmarket economic use values have a long tradition of use in benefit-cost analyses for public projects that either benefit or have adverse impacts on natural resources. Leeworthy and Wiley (1997) expected that the greatest benefits would result from applying the results in evaluations of the many public projects that would be required to fully implement the FKMNS management plan and the Monroe County Comprehensive Plan (focusing on a water quality plan). All these are basically project-orientated.

What follows below is a different perspective calling for different valuation criteria. It links to Peter Wiley's observation (2003) that every US citizen holds a claim to ownership of national resources, but it goes further in a different economic and political context.

### 6.5.4 ECOSYSTEM VALUATION AND THE POLITICS OF CLIMATE CHANGE

The GBR research reveals awareness of the long-term consequences of climate change, although it tackles the actual valuation analysis rather obliquely. Climate change is central to the GBR study, given that it compares a living reef system with a dead one. The research team acknowledges the irreversibility of the loss of any unique environmental natural capital resource (Oxford Economics, p 21).

"Likewise, it can be argued that even willingness to accept valuations does not take into account the non-substitutability of natural capital. By this reasoning, simply compensating people in financial terms of the loss of the GBR cannot provide a true "substitute" for its loss (as, say, an insurance payment for a damaged car might); it is an irreplaceable natural asset. In short, to the extent that the losses from bleaching are irreversible, the values in the current report may be considered conservative given the effective inadequacy of financial compensation.

Even if the full arguments about irreversibility and non-substitutability are not accepted, a partial acknowledgement of them suggests that, to the extent one can measure a consumer surplus associated with the GBR, it is questionable that this can simply be substituted for other activities in the event of bleaching. .. In short, the implications are that arguments about substitute consumption in the face of bleaching face considerable difficulties." (p 22)

The final sentence would ring more true if "face considerable difficulties" was changed to "are meaningless" – quite apart from the fact that the issue is climate change and not "substitute consumption in the face of bleaching." The authors reject (as this writer does) the suggestion by some economists that visitors to the reef might compensate by doing something else instead (go play in another yard?). But while the authors believe that the estimated compensation for the loss of a unique natural resource is "conservative," they give no inkling of how much they think the destruction of the unique resource (for which read GBR) is undervalued. It would certainly exceed the less than $100 per head that users claim they are willing to pay in the GBR analysis (Oxford Economics, p 21).

A $37.7 billion loss is "big" and might look politically impressive, but should it *really* be $50 billion, or $100 billion, or $500 billion? Based on what? The way forward would be to take a radically new look at the nonmarket values of preserving the ecosystems intact for this and coming generations across the planet (existence and bequest values). The assessment would replace what users say they would be willing to pay with what would be needed to preserve the ecosystems. It is safe to predict that these values would be much higher than those based on consumers' willingness to pay to preserve the ecosystems.

The valuation process will be difficult but the growing evidence that ecosystems are interdependent may provide a path. Stakeholders would be increasingly from outside the Florida Keys and living outside the United States, since climate change is global and ecosystems are more interconnected than previously realized. This would provide a global perspective within which to value the local ecosystems. The basis for the re-evaluation must be expert opinion unbiased by personal considerations, rather than users with no detailed knowledge of the intricacies and potential consequences of global climate change making an off-the-cuff assessment of what they would be willing to pay.

The recent report for French President Sarkozy on the shortcomings of GDP statistics agrees that climate change caused by increases in greenhouse gases is a special, truly global issue, going across national boundaries. "Physical indicators of this kind can only be identified with the help of the scientific community." (Stiglitz et al. 2009, pp 18-19, quoted in Appendix 4.)

The valuation process could be based on an agreed set of projections of climate change ranging from global to local impact – perhaps a benign model such as scenario B1 as the base value and an economic growth model such as A1 as the basis for costing lack of action to prevent climate change. A series of workshops would give the best results, allowing participants to spark off each other and develop their concepts. Some of the concepts will be tricky and difficult to determine, and the procedures may have to differ from workshop to workshop to ensure that the full range of local and global views is represented.

It may be appropriate to make the frame of reference the "higher-order" Florida Keys network of interdependent ecosystems discussed in Section 3.3, embracing the whole of the sea- and land-based resources of the Keys. The reefs are important but not alone in the assessment, when we may be losing much more to climate change.

The preservation of ecosystems is accepted as a *sine qua non* in the fight against climate change, and coral reefs are at the forefront in this, and have been at least since the 1998 El Niño event. There is a quantum leap from individual willingness-to-pay measures to political advocacy. Governments, on scientific advice, are becoming convinced that climate change must be tackled politically, on a national and global basis. It therefore moves on to the stage of the political process including all the frustrations we are currently witnessing. It becomes science versus short-term commercial interests and climate change skeptics and deniers, and although connections remain between consumer attitudes and the political process in a democracy, we are on to an altogether different level in the decision-making process.

User assessments of how much they would be willing to pay to preserve a given ecosystem is relevant and good information in its own right, but we have gone on from there to the functioning of a democratic process, where it is not the personal wallet that is at stake, but how we allocate government funds and influence (or are influenced by) polluters and other vested interests. This is the real world situation where stakes are much higher than if a consumer is asked to set a level for his or her willingness to pay. The real world is exceedingly complex, and out of range of individual influence except through the ballot box.

There are important discount rate implications when changing from a project-based to a global climate change perspective of how ecosystems such as coral reefs should be evaluated. Ross Garnaut (2008) did suggest alternative rates of 2.6% and 1.3%, based partly on abstract economic arguments that the world is becoming richer and the marginal utility of extra income/benefit is therefore lower per individual in the future world. However, Garnaut, who was quoted as the source of the "preferred" discount rate of 2.65% in the GBR study, though he personally veered towards half that rate, also pointed to loss of amenities even in a richer world. The future user may not see all the extra wealth benefiting him or her, because much may go on items protecting against the impact of climate change, and life may not be as "happy" as the higher income might have us think. Finally, a hotter world would be both hellish and thwart the projected economic growth (Appendix 4).

The consensus among climate change economists, including Ross Garnaut and Nicholas Stern, is that the discount rate should be low (Appendix 5). It may be appropriate to adopt a social discount rate of 3% for project-based operation, as in NOAA's current evaluations, but in the interest of future generations a rate closer to 1%, or even lower, is more appropriate when assessing the impact of climate change on our grandchildren and further generations beyond.

## 6.6 SCENARIO IMPLICATIONS

**Table 6.29: Schedule for numerical projections for each scenario**

| Scenario A1 (B1, A2, B2) | 2010 | 2035 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Global temperature increase ($^{o}$C) | | | | | |
| Global sea-level rise (cm) | | | | | |
| Global ocean acidification (pH) | | | | | |
| Annual world GDP change | | | | | |
| Keys population | | | | | |
| Population relative to 2010 | | | | | |
| Keys coral cover | | | | | |
| Coral cover relative to 2010 | | | | | |
| Keys area remaining | | | | | |
| Value of Keys area remaining | | | | | |
| Keys income relative to 2010 | | | | | |

The last section of each scenario story in Chapter 7 contains a narrative on the Florida Keys, a standard table containing eleven variables to be projected to 2100 (shown in Table 6.29), and a graph showing the expected paths for the main local variables. Because the scientific and statistical evidence is tending toward what was previously regarded as worst cases, the global numerical projections in Chapter 7 are based on halfway points between the "most likely" and "worst" cases. Even this may be not go far enough, and worst cases should be kept in mind at all times, especially global warming and sea-level rise in view of the risk of tipping points triggering positive feedback effects.

The four global variables chosen for the numerical scenario projections are:

- Global warming

- Sea-level rise
- Ocean acidification
- Change in global economic product.

These are accompanied by the following variables relating to the Florida Keys:

- Population, and population relative to 2010
- Coral cover, and coral cover relative to 2010 (proxy for marine-based tourism)
- Area remaining after inundation (determining population size)
- Value of area remaining after inundation
- Keys income relative to 2010, as a function of coral cover and value of area remaining.

Naturally, there are major uncertainties in these projections. They are estimates that aim to be plausible but cannot at this stage be ultimately related in a formal statistical or mathematical model. No such model has yet been refined globally, or nationally for the United States. We have already discussed an attempt to estimate the present value of the Great Barrier Reef which must be branded unsuccessful for lack of reliable data (Section 6.5), and the considerable range of uncertainties around the "most likely" climate model estimates (Chapter 2).

Before coming to the four scenarios themselves, the final introductory section of Chapter 7 (7.1.5) discusses relationships between the chosen variables, including the connection between global warming and sea-level rise, which is crucial in the Keys context. It then defines a series of "algorithms" between the local Keys variables as a basis for better definitions of the more important interrelationships.

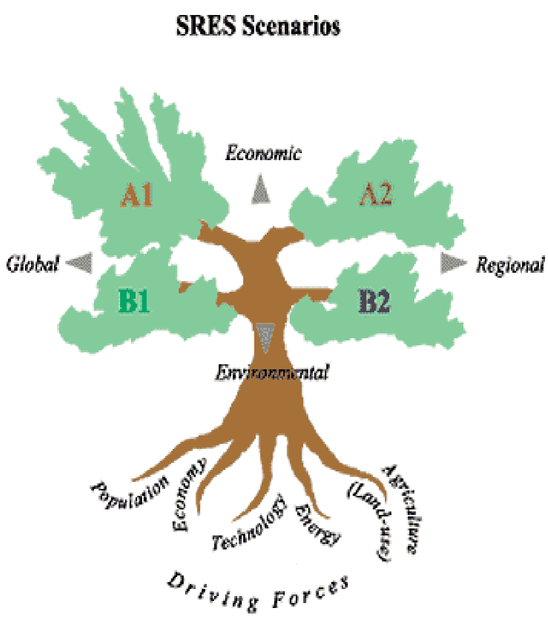
# 7 FOUR SCENARIOS

## 7.1 THE APPROACH

### 7.1.1 MODIFYING THE ORIGINAL SCENARIOS

The original global scenario storylines were sufficiently broad to remain *generally* plausible (Nakicenovic and Swart 2000: *Special Report on Emissions Scenarios* (SRES)). The narratives need some modifications, and as already noted in Chapter 2 (with reference to the detailed discussion in Appendix 3) the expected impact of a given set of global climate change conditions has changed a great deal since the SRES scenarios were written in the 1990s.

*Figure 7.1 schematically illustrates the SRES scenarios, showing how they build on the main driving forces of greenhouse gas emissions. Each scenario family is based on a common specification of the main driving forces. The four scenario families are illustrated in simple terms as branches of a two-dimensional tree. The two dimensions are global versus regional orientation (horizontal), and economic development versus environmental orientation (vertical). In reality, the scenarios are multi-dimensional, reflecting the numerous driving forces and assumptions needed to define any given scenario in a particular modeling approach.*
Source: Nakicenovic and Swart, SRES (2000). Ref.: http://www.ipcc.ch/home_copyright.htm.




The four scenario stories were constructed along two dimensions: "economic development" versus "environmental" (vertical axis in Figure 7.1), and "global" versus "regional" (horizontal axis).

The former dimension seems reasonably unequivocal in terms of scenario development, but the latter gives rise to further thought. Exploring what each scenario means in a 2010 perspective, more than a decade after the stories were written, the realization dawned that the global-regional dimension was influenced by an assumption that globalization is "good" and regionalization is "bad". This has been associated with the thinking of international institutions like the International Monetary Fund, the World Bank, and the World Trade Organization.

Though some of the views of these institutions are becoming more nuanced, as related in the next paragraph, a recent IMF publication could still state: "Based on experiences throughout the world, several basic principles seem to underpin greater prosperity. These include investment (particularly foreign direct investment), the spread of technology, strong institutions, sound macroeconomic policies, an educated workforce, and the existence of a market economy. Furthermore, a common denominator which appears to link nearly all high-growth countries together is their participation in, and integration with, the global economy." (Giovanni et al. 2008)

Yet, many international meetings on trade and finance have been marked by violent demonstrations. This has influenced the rhetoric and practices of international institutions, with the World Bank talking more about poverty and giving the countries it assists a proper decision-making role. Discussing the ways the World Bank in particular has changed its thinking, Joseph Stiglitz concluded in his book, *Globalization and Its Discontents*, that while globalization has brought huge benefits, not least in East Asia, major problems remain. "Globalization today is not working for many of the world's poor. It is not working for much of the environment. It is not working for the stability of the global economy. .. To some, there is an easy answer: Abandon globalization. That is neither feasible nor desirable. .. The problem is not with globalization, but with how it has been managed." (Stiglitz 2002, p 214)

This view is not contested here, but in the assessment of how applicable the four IPCC scenarios are twelve years or so after they were written, the one that may need most revision is B2, the environmentally orientated regionalized scenario story, which shared lowest economic growth in IPCC's Third Assessment Report with the other regionally based scenario, A2. This assessment seems too harsh in today's context, which places more importance on what is increasingly recognized as a misnomer: "non-economic" values such as sociocultural and ecological factors, and an analogous greater wariness of the conventional economic growth indicators. The low assessment of B2 (and burdening it with a rate of population growth to over 10 billion at the end of the century) was probably influenced by the unmodified previous ideas of the international institutions.

The drivers of scenarios can be any relevant sociocultural, technological, economic, ecological and political forces. For climate change, three main elements have modified the interpretation of these forces since the scenarios were first constructed:

1. There is much new evidence that climate change is happening faster than projected in IPCC's Fourth Assessment Report (Pachauri and Reisinger 2007). Scientists now advocate that the emissions of $CO_2$ and other greenhouse gases must be reduced to almost zero within the next decade. Leading climatologists like James Hansen of NASA have concluded that the atmospheric level of about 386 ppm $CO_2$ in 2008 may already be too high to avoid the risk of irreversible and dangerous climate change, and the target should be reduced to 350 ppm $CO_2$ or less (Hansen et al. 2008).
2. The understanding of positive feedback effects is now much improved, due to better climate models and actual observation. There is evidence of Arctic ice melting, ocean acidification, sea-level rise, and permafrost thaw. Such changes are nonlinear and may appear in leaps and bounds as "tipping points" are being reached.
3. No emissions scenario results in an exact impact on temperature and other climate change indicators. Because of complexities in the carbon cycle and other factors that are not fully quantified, there is always a range of variants, resulting in probabilities that the actual change will exceed (or fall short of) the "best" or "most likely" estimate. As temperatures rise, there is an increasing risk, according to Hansen and other climate

scientists, that large-scale nonlinear feedback effects will be triggered or accelerated. These effects could start at what would otherwise be a stabilization level of +3$^{O}$C or lower. The 2007 IPCC report noted that to prevent global warming from exceeding 2$^{O}$C by 2100 requires starting to reduce annual greenhouse gas emissions as early as 2015.

### 7.1.2 THE CLIMATE CHANGE PROCESS

The scenarios must reflect the interactions between the various components of the climate change process. Figure 7.2 is from IPCC's Fourth Assessment Report.

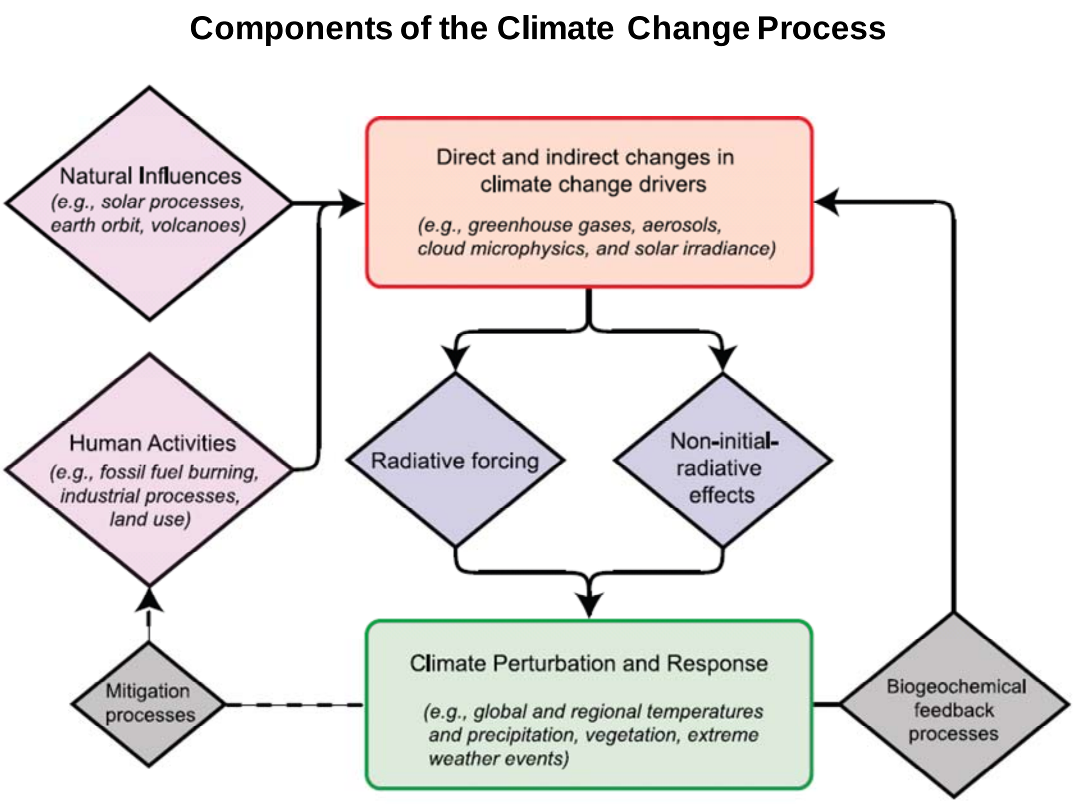



*Figure 7.2: Linkages between radiative forcing and other aspects of climate change assessed by the IPCC. Human activities and natural processes, dominated by the former, cause direct and indirect changes in the drivers of climate change. These result in positive or negative changes in radiative forcing and cause some non-initial radiative effects, such as changes in evaporation. Radiative forcing and non-initial radiative effects lead to climate perturbations and responses. Coupling among biogeochemical processes leads to feedbacks from climate change to its drivers, for example the change in wetland emissions of $CH_4$ that may occur in a warmer climate. The potential approaches to mitigating climate change by altering human activities (dashed lines) are left out of the scenarios but are obviously vital factors and part of the policy recommendations in this report.* Source: IPCC Working Group I report (Forster et al. 2007).

Radiative forcing compares the strength of different human-caused (anthropogenic) and natural agents (generated by its own internal dynamics) in causing climate change. It is defined as the change in net irradiance at the tropopause, measured in watt per square meter ($Wm^{-2}$) and designated $\Delta F$. To provide a simple measure for quantifying and ranking the many different influences on climate change, it is related linearly to the global mean atmospheric surface temperature change $\Delta T_s$ via the equation $\Delta T_s = \lambda \Delta F$, where $\lambda$ is the climate sensitivity (the change in global mean surface temperature that would result from a sustained doubling in atmospheric $CO_2$-e – carbon dioxide-equivalent greenhouse gases – from the pre-industrial level). The radiative forcing $\Delta F$ is positive if the global mean is rising, and negative if falling.

The contribution of greenhouse gases is dominated by carbon dioxide ($CO_2$), whose global mean in 2005 was 379 parts per million (compared with 260 ppm in 1750 and reaching 387 ppm in 2009). Its radiative forcing was +1.66 (±0.17) $Wm^{-2}$, where the uncertainty (±0.17) represents 95% probability limits. This represents three-quarters of total radiative forcing, which increased by 9% between 1995 and 2005, to +2.63 (±0.17) $Wm^{-2}$. The main remaining contributions, apart from soot particles comparable in impact to the methane emissions, were from methane ($CH_4$), with a global mean in 2005 of 1,774 parts per billion and radiative forcing at +0.48 (±0.05) $Wm^{-2}$, and nitrous oxide ($N_2O$), with a global mean in 2005 of 319 ppb and radiative forcing at +0.16 (±0.02) $Wm^{-2}$. The remaining greenhouse gases were mainly hydrochlorofluorocarbons (HCFCs), and chlorofluorocarbons (CFCs), which at the time of the Fourth Assessment Report were beginning to decline.

Paleoclimatic evidence shows that current atmospheric contents of $CO_2$ and $CH_4$ far exceed the natural range over the past 800,000 years according to Antarctic ice core data (Karl et al. 2009). Global sea levels, when Arctic summers were up to $5^oC$ warmer, were probably 4-6 m higher during the last interglacial period 125,000 years ago than is the case now. This and other paleoclimatic evidence makes it *virtually certain* that global temperatures during coming centuries will not be significantly influenced by naturally induced cooling. It is *very unlikely* that the Earth would naturally enter another ice age for at least 30,000 years (Jansen et al. 2007).

Emissions of carbon dioxide, methane, nitrous oxide and of reactive gases such as sulfur dioxide, nitrogen oxides, carbon monoxide and hydrocarbons, which lead to the formation of secondary pollutants including aerosol particles and tropospheric ozone, have increased substantially in response to human activities. As a result, biogeochemical cycles have been significantly disturbed. Nonlinear interactions between the climate and biogeochemical systems could amplify (positive feedbacks) or attenuate (negative feedbacks) the disturbances produced by human activities. (Denman et al. 2007, which is also the source of the next one-and-a-half paragraphs).

One example is the change in the land surface (vegetation, soils, water) resulting from human activities, which can affect regional climate through shifts in radiation, cloudiness and surface temperature. Another crucial coupling between biogeochemistry and radiative forcing is the carbon cycle between the atmosphere, oceans and land and coastal biosphere. The removal of $CO_2$ from the atmosphere involves a range of processes with different time scales. About 50% will be removed from the atmosphere within 30 years, a further 30% within a few centuries, but the remaining 20% will hang around for many millennia.

Absorptions of $CO_2$ into the ocean has lowered the pH (increased the acidity) from 8.2 by to 8.1 since 1750, thus reducing the calcification of shell-forming organisms and, in the long term, the dissolution of carbonate sediments. While the reduction in pH at first glance doesn't look much, the scale is exponential: each whole pH value, say 8, is 10 times more acidic than the next higher whole pH value. The already recorded increase in acidity indicates a 30% increase in the number of hydrogen ions ($H^+$) present in the water – a very significant increase in acidification. In a "business-as-usual" scenario the average ocean surface water pH is expected to decrease dramatically by a further 0.3-0.4 units (Doney et al. 2009, p 170).

Over the past decade since the Third Assessment Report was prepared, the confidence in the model estimates of future climate change has increased due to a range of advances. These include developments in the evaluation of climate feedbacks as well as improved model formulations, model climate simulations, and analytic methods (Randall et al. 2007).

In summary, the understanding of climate change has advanced significantly. The understanding of human-induced warming of the climate system was widespread by the time of the Fourth Assessment Report, and it was *extremely unlikely* that the global pattern of warming during the past half century can be explained without external forcing, and *very unlikely* that it was due to natural causes only. It was *likely* that there had been a substantial anthropogenic contribution to temperature increases in all continents except Antarctica since the middle of the $20^{th}$ century (Hegerl et al. 2007).

As this report notes repeatedly, events have kept pushing the findings of the Fourth Assessment Report towards or beyond the upper boundaries of its projections. The individual chapters quoted above from the Working Group I section of the Fourth Assessment Report give further detail such as the anthropogenic influence on other parts of the climate system including Arctic sea-ice content and glacial retreat, according to the knowledge accumulated by early 2007.

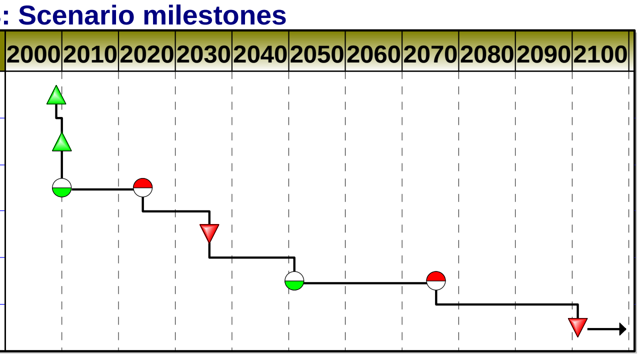
### 7.1.3 GLOBAL SCENARIO STORIES

All storylines are reproduced verbatim from the SRES report (Nakicenovic and Swart 2001), apart from omitting most of the references to other scenarios given in the source. These examples are interesting but detailed references can be identified in the source document.

The storyline is followed by a section on its current plausibility ("Would the scenario story have been written this way in 2010?"). The evaluation takes into account that scenarios, to be useful, need a sufficiently wide span to cover all plausible worlds. Some aspects of the scenarios may appear extreme, but the issue is whether they remain inside the realm of what could plausibly happen if no corrective action is taken. The subsequent section then asks whether modifications are needed in light of the review of changing physical, economic and technological factors in Appendices 3 to 6, which is an advance on previous scenario analysis.

**Figure 7.3: Scenario milestones**

| STAGE | Year |
|---|---|
| Update SRES scenarios | 2009 |
| Scenarios start | 2010 |
| Path towards main scenario story | 2020s |
| "Near term" milestone | 2035 |
| Intermediate long-term milestones | 2050/75 |
| Final milestone and further outlook | 2100+ |



A brief pathway for each scenario is then outlined from 2010 to the time when the storyline kicks in, say, by the mid to late 2020s (Figure 7.3). The global path is outlined to 2100 on the assumption that no attempt is made to mitigate the impact of climate change.

As part of the description of the global path and the implications for the Florida Keys, a "near-term" milestone is set for 2035 as recommended by Moss et al. (2008), who are preparing the scenario principles for IPCC's Fifth Assessment Report. The authors say that key issues for the "near-term" analysis will eventually include identifying immediate risks, developing corresponding adaptive capacity, reducing vulnerability, making efficient investments to cope with climate change, developing low-emission technologies and energy conservation, and preserving and improving sinks (all covered in the review of technologies in Appendix 6).

The penultimate milestone for the storylines is the "long-term" view of 2100 (supplemented in Figure 7.3 by intermediate markers in 2050 and 2075). In the long-term view, Moss et al. (2008) note that the policy focus shifts towards evaluating climate targets to avoid risks from climate change impacts, improving the understanding of risks of major geophysical and biogeochemical change and feedback effects, and adopting strategies for adaptation, mitigation, and development that are robust over the long term to remaining uncertainties. Scenarios of different rates and magnitudes of climate change will provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems.

While the scenarios are presented in this chapter as they would play out without remedial action, the points made in connection with the "near-term" and "long-term" views are useful guidelines for the policy recommendations in Chapter 8.

The 2100 milestone is called "penultimate" to leave space for a quick view into the future from the end of the century focusing on matters such as coral cover and sea levels, human population, economic and social trends, and wealth distributions across the planet. The idea of a 'view beyond' follows recent practice, including a perspective on reef development in the Coral Triangle between Indonesia, the Philippines and the Solomon Islands over the next three centuries (Hoegh-Guldberg et al. 2009). Stern (2009) also notes that some stabilization paths may continue well into the 22nd century.

### 7.1.4 Scenario stories for the United States

Next, the focus in each scenario section (7.2 to 7.5 below) is narrowed to a brief sketch of a future United States – kept fairly unspecific because Florida and the Keys themselves are microcosms of America, albeit microcosms at particularly high risk. The US scenarios are based on Cullen Murphy's book *A New Rome* (Murphy 2007), which ends with an outline of three scenarios (see addendum at the end of Appendix 3). He contrasts these with what he calls, in line with his Roman theme, "The Titus Livius hundred-year workout plan". This environmentally and sociologically friendly scenario has four components:

1. *Instill an appreciation of the wider world*, helped by immigration and the influx of foreign students. There is no substitute for fluency in another language. "Every educated person in the Roman Empire spoke at least two languages, and so did the strivers in the, uh, immigrant hordes. Americans have their priorities backward. They worry needlessly

about the second part: whether the immigrants will ever learn English. They should be worrying about the second part: whether the elites will ever speak anything else."

2. *Rely on government proudly for the big things it can do well*, rather than treating it as a necessary evil. Governments act as a counterforce to inequality, and can be held accountable in ways the private sector cannot. "It takes some imagination to see how corrosive privatized government will prove to be many decades down the road – and that's another thing: start thinking in centuries."

3. *Fortify the institutions that promote assimilation*. America already has a powerfully absorptive and transformational domestic culture, but it needs to be reinforced rather than undermined. "In Massachusetts recently a debate broke out over whether the children of illegal aliens should be allowed to pay the low "in-state" rate at public colleges and universities. The answer should have been yes. The answer to public schools and public health services for immigrants should always be yes – these do more, with less, than any fence can accomplish."

4. *Take some weight off the military*, eliminating some of the things we need an army for. Rome turned into a state whose entire purpose was military. "America is still free to make choices. It can let regional powers shoulder more of the burden. One unilateral decision above all would buy a lot of breathing room, and ought to be made regardless: to adopt a long-range energy policy based as much as possible on renewable resources, allowing us to pull away, eventually, from military oversight of the entire Middle East." (Murphy called this a hundred-year project – "Rome wasn't built in a day." But we would have to build a long-range energy policy in much less than a century.)

### 7.1.5 FROM GLOBAL TO LOCAL SCENARIOS

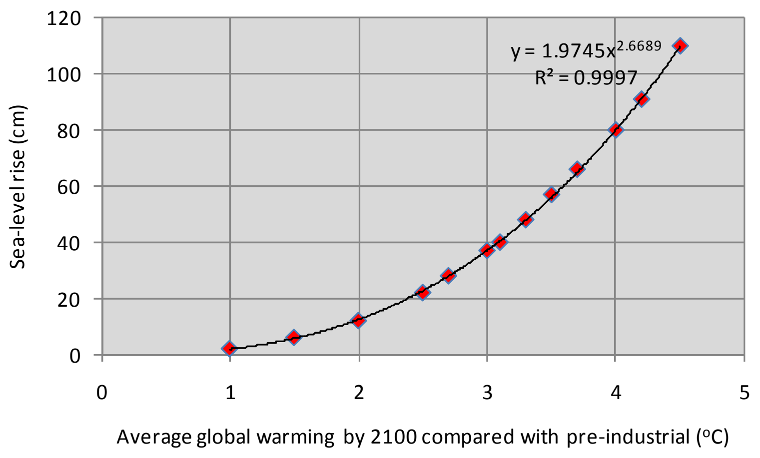
One major problem when progressing to the local level is to retain a quantitative framework, for example by identifying "algorithms" to link the various variables. The purpose is to lend credence to the local projections, to the extent that plausible interrelationships can be found.

The greatest change since the publication of IPCC's *Fourth Assessment Report* (Pachauri and Reisinger 2007) concerns the impact on sea levels under global warming, which is of vital significance to the Florida Keys for obvious reasons. In the B1 scenario, the median global temperature rise was 1.8$^{O}$C and the mid-point sea-level rise 28 cm. In the worst-case A2 and A1FI scenarios, the global mean temperature was calculated to increase by 3.4$^{O}$C and 4.0$^{O}$C, respectively, and the mid-point sea-level rise was 37 and 43 cm, respectively. The difference between the best- and worst-case scenarios is expected to be much wider today, as illustrated by Chris Bergh's investigation of the impact of sea-level rise on the Florida Keys, which is a key source for the current section and mentioned in several other connections in this report including the policy recommendations in Chapter 8 (Bergh 2009).

This section discusses the relationships between the global and local factors shown in Table 6.29 at the end of the previous chapter. The four global factors are interrelated: global warming, sea level, ocean acidity, and world GDP.

The global temperature increase is the main external or "exogenous" variable, defined by the IPCC in relation to each scenario and discussed in detail in Appendix 3. Its relationship to the world economy is explained in Appendix 4, including the constraints on growth if global warming accelerates as projected. The global ocean chemistry measured by pH has been projected to change from 8.1 to 7.7 in a worst-case scenario (Doney et al. 2009). This has been adopted as a guide to the economically orientated scenarios, A1 and A2, with lesser changes projected for the B1 and B2 cases.

**Figure 7.4: Sea-level rise versus global warming**




The crucial link in the Florida Keys context, however, is between global warming and sea-level rise. Adopting the more pessimistic views emerging since 2007, Figure 7.4 suggests that the link can be described by a power curve. Estimated value pairs include 12 cm sea-level rise at 2$^{O}$C warming, 37 cm at 3$^{O}$C, 57 cm at 3.5$^{O}$C, 80 cm at 4$^{O}$C, and 110 cm at 4.5$^{O}$C. These values are generally in tune with recent literature, including the assumptions Bergh (2009) made for sea-level rise in the Florida Keys, and comparison of global warming trends and sea-level change over the 21$^{st}$ century (Rahmstorf 2007).

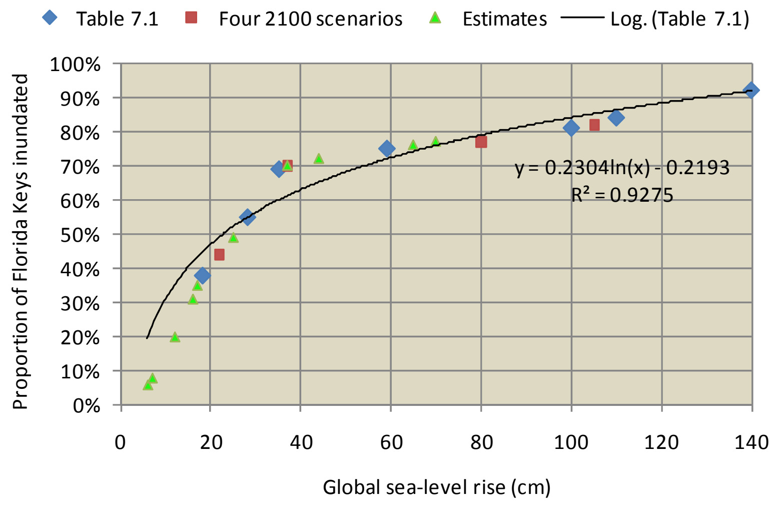
**Table 7.1: Projected areas and values of Florida Keys land at risk**

| Global sea-level rise | At risk (area) | | At risk (value) | |
|---|---|---|---|---|
| | 000 acres | Relative | $ billion | Relative |
| 18 cm | 58.8 | 38% | 11.0 | 26% |
| *28 cm* | *85.0* | *55%* | *15.2* | *35%* |
| 35 cm | 106.0 | 69% | 18.7 | 43% |
| 59 cm | 115.0 | 75% | 21.9 | 51% |
| 100 cm | 124.0 | 81% | 26.7 | 62% |
| *110 cm* | *129.0* | *84%* | *29.0* | *67%* |
| 140 cm | 142.0 | 92% | 35.1 | 82% |
| | Total area in 2008 (000 acres) | | Total value in 2008 ($ billion) | |
| Original totals | 154.0 | 0% | 43.0 | 0% |

Source: Bergh (2009), Table 1, p 25 (28 cm and 110 cm interpolated)

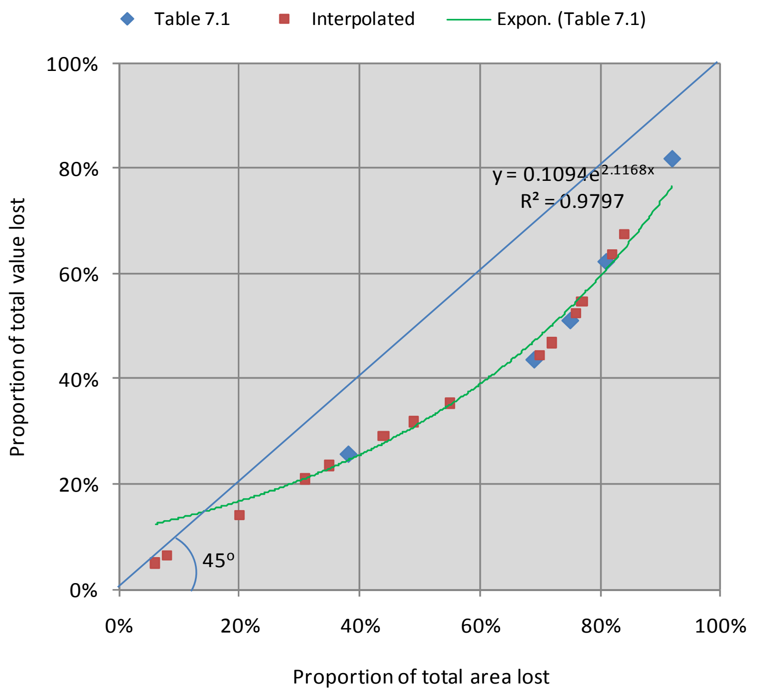
This provides the key to the relationship between global sea-level rise and the degree of inundation expected in the Florida Keys. Keys-wide data are shown in Table 7.1, derived from the main table on p 25 of Bergh's projections for the Florida Keys (2009). Considering first the relationship between global sea-level rise and the area at risk in the Florida Keys, the latter increases from 38% of the total Keys area at the *most optimistic* B1 scenario (rather than the *most likely* B1 scenario), which has the global sea-level increase at 18 cm by the end of the century. At the "extreme Rahmstorf projection" of a 140 cm increase in the global sea level, 92% of the Keys area is considered at risk. The values from Table 7.1 are plotted as blue diamonds in Figure 7.5, which also shows the four estimated end points for each scenario (shown as red squares), and various interpolated and extrapolated estimates (green triangles). The correlations are approximated by a logarithmic fit but the data clearly fall into two groups:

**Figure 7.5: Global sea-level rise and Keys area covered**




- ➢ Inundation of the Keys is expected to proceed along a more or less straight line (to 70%) as the global sea-level rise reaches about 35 cm.
- ➢ It then proceeds at a much slower pace towards 92%, reached at the "extreme Rahmstorf projection" of 140 cm global sea-level rise.

**Figure 7.6: Keys land loss by area versus value**




These features would be associated with the particular elevation patterns of the Keys as revealed by Chris Bergh's analysis. The preponderance of very low-lying areas and a minority of higher areas more resistant to flooding would help explain the pattern.

Bergh's research also shows that the relative physical land loss exceeds the relative loss of the value of the land. The relationship between loss of land and loss of value is best described by an exponential curve (Figure 7.6). Again, the evidence comes from the main table in Bergh (2009, p 25). Compared with the 45$^{O}$ line from the origin of the graph which would equate the proportions of area and value loss, the estimated loss in value since 2010 at, say, 40%, is more than 20 percentage points below the proportion of total loss of area (60%), before the gap starts to narrow between the two measures, as the exponential curve trends back towards the 45$^{O}$ line again.

**Table 7.1 supplement: Lower, Middle and Upper Keys**

**Lower Keys**

| Global sea-level rise | At risk (area) 000 acres | At risk (area) Relative | At risk (value) $ billion | At risk (value) Relative |
|---|---|---|---|---|
| 18 cm | 11.0 | 18% | 2.6 | 12% |
| 35 cm | 49.4 | 82% | 8.8 | 42% |
| 59 cm | 54.4 | 90% | 11.0 | 53% |
| 100 cm | 56.3 | 93% | 13.0 | 62% |
| 140 cm | 58.0 | 96% | 15.8 | 76% |
| Lower Keys | 000 acres | | $ billion | |
| 2008 | 60.5 | 0% | 20.9 | 0% |

**Middle Keys**

| Global sea-level rise | At risk (area) 000 acres | At risk (area) Relative | At risk (value) $ billion | At risk (value) Relative |
|---|---|---|---|---|
| 18 cm | 4.4 | 25% | 0.8 | 12% |
| 35 cm | 9.5 | 54% | 1.9 | 29% |
| 59 cm | 11.2 | 64% | 2.6 | 41% |
| 100 cm | 12.6 | 72% | 3.5 | 55% |
| 140 cm | 17.3 | 99% | 6.0 | 94% |
| Middle Keys | 000 acres | | $ billion | |
| 2008 | 17.5 | 0% | 6.4 | 0% |

**Upper Keys**

| Global sea-level rise | At risk (area) 000 acres | At risk (area) Relative | At risk (value) $ billion | At risk (value) Relative |
|---|---|---|---|---|
| 18 cm | 43.3 | 57% | 7.6 | 48% |
| 35 cm | 47.5 | 62% | 8.0 | 51% |
| 59 cm | 49.6 | 65% | 8.3 | 53% |
| 100 cm | 55.6 | 73% | 10.1 | 64% |
| 140 cm | 67.1 | 88% | 13.2 | 84% |
| Upper Keys | 000 acres | | $ billion | |
| 2008 | 76.1 | 0% | 15.7 | 0% |

The overall results in Table 7.1 do not apply universally across the Keys. The main table in Bergh (2009, p 25) displays separate findings for the three main parts of the Florida Keys as shown in the supplement to Table 7.1 to the left.

The Lower Keys (60,500 acres) before any land loss account for 39% of the 154,000 acres of the Florida Keys, compared with 11% in the Middle Keys and the remaining half in the Upper Keys. In value terms, however, the Lower Keys in 2008 accounted for 49% of the total compared with 15% for the Middle Keys and 36% in the Upper Keys.

If the global sea level rose by 35 cm, which according to Figure 7.5 is close to the point where rapid inundation in response to global sea-level rise gives way to a slower process, 82% of the Lower Keys would be at risk, compared with 54% of the Middle Keys, and 62% of the Upper Keys. In value terms, the proportions at risk at 35 cm global sea-level rise would be 42%, 29%, and 51%, respectively.

There are clearly quite large differences between the estimated rates of inundation from area to area and the estimated value of the areas at risk. The Middle and Upper Keys, for example, are relatively less at risk up to what is regarded to be beyond the worst-case scenario in this report (but still conceivable), a 100 cm global sea-level rise. At this level, 72-73% of the land in these areas would be at risk, compared with 93% in the Lower Keys. If a 140 cm rise happened, however, little would remain of the Middle Keys, compared with 4% of the Lower Keys and as much as 12% of the Upper Keys.

The relationship with values, however, is more complex. Figure 7.6 showed that in the Keys as a whole, the maximum difference between land loss and value loss increases to over 20 percentage points with land loss at over 60% and value loss below 40%. In the Lower Keys, the area at risk at 35 cm global sea-level rise is 82% of the 2010 level but only 42% in value terms, a difference of fully 40 percentage points. Even in the extreme worst case, a global sea-level rise of 140 cm and 96% of the total Lower Keys area lost (4% remaining), 24% of the total initial value would remain. Key West is evidently expected to remain an important asset, even in the worst of changing climates. The same clearly cannot be said about the rest of the Lower Keys.

In the Middle Keys, the gap between proportion of initial area at risk and the corresponding proportion of value at risk widens to 25 percentage points at 35 cm global sea-level rise, while the difference is only 11-12 percentage points in the Upper Keys, where it occurs between 35 and 59 cm global sea-level rise. The Upper Keys, however, would still retain the largest proportion of original land under the

**Table 7.2: Population and income implications?**

| Year | Scenario | | | |
|---|---|---|---|---|
| | A1 | B1 | A2 | B2 |
| **A: Population declines in proportion to area (thousand)** | | | | |
| 2010 | 72.0 | 72.0 | 72.0 | 72.0 |
| 2035 | 57.6 | 67.7 | 49.7 | 66.2 |
| 2050 | 21.6 | 57.6 | 20.2 | 49.7 |
| 2075 | 18.0 | 46.8 | 16.6 | 36.7 |
| 2100 | 16.6 | 40.3 | 13.0 | 21.6 |
| **B: Population relative to 2010** | | | | |
| 2010 | 100.0% | 100.0% | 100.0% | 100.0% |
| 2035 | 80.0% | 94.0% | 69.0% | 92.0% |
| 2050 | 30.0% | 80.0% | 28.0% | 69.0% |
| 2075 | 25.0% | 65.0% | 23.0% | 51.0% |
| 2100 | 23.0% | 56.0% | 18.0% | 30.0% |
| **C: Gross income declines in proportion to remaining value** | | | | |
| 2010 | 100.0% | 100.0% | 100.0% | 100.0% |
| 2035 | 86.0% | 95.0% | 79.0% | 93.5% |
| 2050 | 55.6% | 86.0% | 53.2% | 79.0% |
| 2075 | 49.1% | 76.5% | 45.3% | 68.2% |
| 2100 | 45.3% | 71.0% | 36.5% | 55.6% |
| **D: Index of wealth per person from the above** | | | | |
| 2010 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2035 | 107.5 | 101.1 | 114.5 | 101.6 |
| 2050 | 185.2 | 107.5 | 190.0 | 114.5 |
| 2075 | 196.4 | 117.7 | 197.1 | 133.6 |
| 2100 | 197.0 | 126.7 | 202.5 | 185.2 |

Source: See text

extreme worst-case scenario of 140 cm sea-level rise (12%, compared with 4% for the Lower Keys and only 1% for the Middle Keys).

One final set of relationships remains to be analyzed (Table 7.2). Assuming that population declines in proportion to the area lost, the drop is smallest in the B1 scenario (44%) and largest in scenarios A1 and A2 (77% and 82%, respectively). The environmentally friendly regional scenario B2 also dips quite strongly in the final quarter of the century if we apply this model.

The one-to-one ratio between declining population and land area makes most sense in the context of carrying capacity but not between gross income and remaining land values. It works as a useful illustration if carrying capacity is already stretched to the limit, which seems to be a sensible working hypothesis.

There is less justification for applying a rule that gross income declines in proportion to the remaining value of the Keys land, which we have seen shows a smaller drop than the land area. Panel C of Table 7.2 suggests that B1 shows the smallest reduction in gross income under this assumption, followed by B2, A1 and A2. The model proves to be of doubtful validity when we apply the final logic of constructing an index of per capita wealth based on Panels B and C of Table 7.2. Panel D suggests that the index doubles for both the economic scenarios, A1 and A2, with B2 not far behind. Scenario B1 lags far behind these other indices, with a 26% increase by the end of the century.

In conclusion, while the previous "algorithms" developed in this section make reasonable sense, the assumptions underlying Table 7.2 must be carefully considered, especially the relationship between value loss and total income or wealth in the Keys.

One local indicator that has not yet been mentioned in this section is coral cover. Although marine-based tourism declined relative to history-based tourism between 1995-96 and 2007-08, it is considered to be of continuing importance for a range of economic and scientific reasons. Scientists generally agree that the coral reefs would suffer beyond survival in a "business-as-usual" scenario, which suggests that the cover would disappear in the A1 and A2 scenarios.

It is rational to assume, however, that the emphasis on reef resilience initiated by the TNC, the FKNMS, the State of Florida, Monroe County, community groups and others would bear fruit – coral cover in the B1 and B2 scenarios is therefore assumed to remain, though at lower than current levels. We have found no "algorithms" to estimate what levels would be reasonable, and the projected levels are not sacrosanct. But the continued existence of a significant part of the reef is important in itself, whether the ultimate cover is 3%, 4% or 5%. The assumption made here is that the cover is reduced to 3.5% in scenario B1, and to 3.0% in B2 (compared with 6,4% currently).

In conclusion, the lack of additional carrying capacity imposes such a strain that is seems plausible to assume that the local population will decline in proportion with the land loss as inundation occurs. This is the assumption adopted for the population projections under each scenario.

This leaves the dilemma of how to estimate local income trends from insufficient data. Two considerations provide guidance:

- Assuming that the projections of residual land values are realistic (dominated by Key West), it is plausible that an increasing proportion of these values will benefit people, corporations and institutions who are not residents of the Florida Keys. While it is impossible to put a figure on this proportion, this will inevitably reduce the income and wealth of local residents from the potential suggested by Table 7.2.
- Coral cover can be seen as a partial proxy for marine-based tourism value, especially since other indicators such as fish stock have also declined. In addition, a relatively vigorous tourist industry may be instrumental in retaining a higher share of the real-estate wealth in the Keys, though this would be difficult to measure.

We have concluded that local income or wealth will be governed by two factors: the value of remaining land in Key West and the rest of the Florida Keys, and the remaining coral cover, acting as a proxy for marine-based tourism strength. With no further evidence on hand, a simple average of the two factors is used to derive an illustrative (rather than powerful) “algorithm” for determining the trend in total income or wealth in the Keys.

The relationships will be taken into account for possible inclusion in the local Keys scenario stories (Sections 7.2.7, 7.3.7, 7.4.7, and 7.5.7).

## 7.2 Scenario A1: Global economic focus

### 7.2.1 The IPCC storyline

The A1 storyline is a case of rapid and successful economic development, in which regional average income per capita converge – current distinctions between "poor" and "rich" countries eventually dissolve. The primary dynamics are:

- Strong commitment to market-based solutions.
- High savings and commitment to education at the household level.
- High rates of investment and innovation in education, technology, and institutions at the national and international levels.
- International mobility of people, ideas, and technology.

The transition to economic convergence results from advances in transport and communication technology, shifts in national policies on immigration and education, and international cooperation in the development of national and international institutions that enhance productivity growth and technology diffusion.

This may be the type of scenario best represented in recent literature. Such scenarios are dominated by an American or European entrepreneurial, progress-oriented perspective in which technology, especially communication technology, plays a central role. Various scenarios designed in 1995 share features with A1. They emphasize market-oriented solutions, high consumption of both tangible and intangible commodities, advanced technology, and intensive mobility and communication. In some examples of this type of scenario, high economic growth leads to shifts of economic power from traditional core countries to the current economic "periphery”. The [previous] IPCC Scenarios IS92a and IS92e are well-known examples of futures with high levels of economic growth. IIASA [International Institute for Applied Systems Analysis] and [the] World Energy Council jointly developed three high growth scenarios that share assumptions on rapid technological progress, liberalized trade markets, and rising income levels.

In the A1 scenario family, demographic and economic trends are closely linked, as affluence is correlated with long life and small families (low mortality and low fertility). Global population grows to some nine billion by 2050 and declines to about seven billion by 2100. The average age increases, with the needs of retired people met mainly through their accumulated savings in private pension systems.

The global economy expands at an average annual rate of about 3% to 2100, reaching around US$550 trillion (expressed in 1990 dollars). This is approximately the same as average global growth since 1850, although the conditions that lead to this global growth in productivity and per capita incomes in the scenario are unparalleled in history. Global average income per capita reaches about US$21,000 by 2050. While the high average level of income per capita contributes to a great improvement in the overall health and social conditions of the majority of people, this world is not necessarily devoid of problems. In particular, many communities could face some of the problems of social exclusion encountered in the wealthiest countries during the 20$^{th}$ century, and in many places income growth could produce increased pressure on the global commons.

Energy and mineral resources are abundant in this scenario family because of rapid technical progress, which both reduces the resources needed to produce a given level of output and increases the economically recoverable reserves. Final energy intensity (energy use per unit of GDP) decreases at an average annual rate of 1.3%. Environmental amenities are valued and rapid technological progress "frees" natural resources currently devoted to provision of human needs for other purposes. The concept of environmental quality changes in this storyline from the current emphasis on "conservation" of nature to active "management" of natural and environmental services, which increases ecological resilience.

With the rapid increase in income, dietary patterns shift initially toward increased consumption of meat and dairy products, but may decrease subsequently with increasing emphasis on the health of an aging society. High incomes also translate into high car ownership, sprawling suburbia, and dense transport networks, nationally and internationally.

Several scenario groups considered in the A1 scenario family reflect uncertainty in the development of energy sources and conversion technologies in this rapidly changing world. Some scenario groups evolve along the carbon-intensive energy path consistent with the current development strategy of countries with abundant domestic coal resources. Other scenario groups intensify the dependence on (unconventional) oil and (in the longer-run) natural-gas resources. [These groups were merged into the fossil-intensive A1FI scenario.] A third group envisages a stronger shift toward renewable energy sources and conceivably also toward nuclear energy [A1T]. A fourth group (which includes the A1B marker scenario) assumes a balanced mix of technologies and supply sources, with technology improvements and resource assumptions such that no single source of energy is overly dominant. The implications of these alternative development paths for future greenhouse gas emissions are challenging: the emissions vary from the carbon-intensive to decarbonization paths by at least as much as the variation of all the other driving forces across the other SRES scenarios.

### 7.2.2 WOULD THIS SCENARIO STORY HAVE BEEN WRITTEN DIFFERENTLY IN 2010?

Following the response to this question, Section 7.2.3 will examine possible physical influences on the A1 scenario, from the analysis in Appendices 3 to 6.

Scenarios should range to the limits of the plausible – bearing in mind that all four scenarios are considered equally likely to occur and would run their course in the absence of any mitigating action. There may nevertheless have been a shift in perceptions compared with the early to mid 1990s when the scenarios were written.

The broadening range of developing countries growing into greater economic prominence represents a significant change. The term 'BRIC' was applied in 2001 to Brazil, Russia, India, and China (two other nations, Mexico and South Korea, were considered more developed). *The Economist* has called the BRIC countries the 'trillion-dollar club' since they are the only nations outside OECD whose GDP exceed that amount (*The Economist* 2010 – the next in line, Mexico and South Korea weighed in at about $800 billion in 2009, like OECD member Australia at $900 billion approaching the trillion-dollar mark). A new term, BIICS, has been coined to comprise Brazil, China, India, Indonesia, and South Africa (OECD 2010). Russia was excluded from this group only because of its status as an accession candidate for OECD membership (together with Chile, Estonia, Israel, and Slovenia).

By way of background, the main critics of the IPCC scenarios, with the largest potential effect on A1, were Castles and Henderson (2003), because incomes were compared using market exchange rates (MER) rather than a purchasing-power-parity (PPP) basis which compares income levels based on how much of a country's currency would buy what one dollar would buy in the United States. There is less difference between national per capita incomes using PPP than using MER, so allegedly less catching up to do by poorer countries.

Castles' and Henderson's criticism was refuted (Nakicenovic et al. 2003), and the debate appears to be closed. Our own comments follow on what may have changed by 2010:

- The assumption that incomes would converge between all countries has always seemed to verge on heroic, especially as far as the least-developed countries are concerned, two-thirds of them in Sub-Saharan Africa, and the remainder ranging from Haiti to Afghanistan. The global economic growth projections are also very high, accelerating to 4.7% per annum through the 2020s before slowing towards 1.7% pa between 2080 and 2100 when the global population is falling (Appendix 4, Table 2). The IPCC's A1 growth projections, in all three variants, are the highest of all scenarios.
- Climate policy may be changing, with less emphasis on penalizing schemes including cap-and-trade and more – or at least a joint emphasis – on a straight carbon tax and incentives, as expressed in a study led by Gwyn Prins of the London School of Economics (Prins et al. 2009) and followed up after the "crash" in climate change policy in Copenhagen in December 2009 (Prins et al. 2010). Although the scenario rules don't allow climate policy to be changed during the period of the scenario, the different policy directions should be taken into account in the initial definition of each scenario to highlight their divergent paths.
- The America-centric or Eurocentric bias that the narrative admits to would be less acceptable today, as we witness the dramatic ascendancy of very different economies

and cultures, led by China and India. It remains plausible to assume that these countries will participate in a globalized economic growth society, but the description of their societal patterns, and what these mean, would need to be more nuanced than expressed in the current narrative. For example, China's efforts in the areas of mitigation motivated by its fragile environment (massive railroad development, development of solar and other new technologies) have to be judged against the impact of its equally massive development of coal-fired energy projects, hoping without certainty that carbon capture and storage (CCS) technology will become cost-effective in time. Again, the outcome would differ markedly between scenarios.

- As the concern about ecosystems and possible domino effects is increasing, the assumed change from the current emphasis on "conservation" to active "management" of natural and environmental services needs rethinking and rephrasing. It is doubtful that the "management" envisaged by the 1990s scenario builders would still be considered likely to increase ecological resilience, given the growing understanding of how ecosystems are interconnected and how positive feedback effects develop from tipping points in the climate models.

Other points might be added, and a globalized growth scenario would have to start from much more detailed analysis of the current situation than can be done here – it is impossible to write a whole new storyline within the confines of this project. Looking at the storyline as distinct from the observed greater threat from climate change, economic management becoming more complex, and the development of technology over the past decade, there can be no dispute that the scenarios must include a high growth version based on faith in technology as the great fixer, while relegating environmental policies, and sociocultural policies as well, to lesser roles.

### 7.2.3 CURRENT PHYSICAL, ECONOMIC AND TECHNOLOGICAL INFLUENCES

The scientific assessment of climate change – shared by leading climate change economists – has become progressively more pessimistic over the past decade, reaching a position where global average warming above 2$^{O}$C is considered dangerous, and atmospheric $CO_2$ should be reduced from present levels to 350 ppm or less. This is the story in Appendix 3.

According to the Fourth Assessment Report (Appendix 4, Table 2), the most likely temperature change in the marker scenario of "balanced" fossil and renewable fuel technologies (including nuclear) is 2.8$^{O}$C, and the worst case within the range of projections 4.4$^{O}$C. In the fossil-intensive variant, A1FI, the most likely outcome is 4$^{O}$C and the worst case 6.4$^{O}$C. If renewables should start to dominate energy supplies in the "A1T" scenario variant, the most likely case is 2.4$^{O}$C and the worst case 3.8$^{O}$C. The then assumed $CO_2$ levels in 2100 were 710 ppm (A1B), 964 ppm (A1FI), and 578 ppm (A1T).

Ignoring that projections since 2007 would generate higher average temperature changes for the A1 scenarios (more so than for other scenarios, especially B1), the economic growth model based on average global warming in Appendix 4 (Figure 5) suggests that in the "most likely" case the balanced technology marker scenario A1B would show uninterrupted growth through the century, but the fossil-intensive scenario A1FI would turn negative from 2080. In the worst case based on the Fourth Assessment Report, A1FI turns down from the 2050s, the marker scenario A1B from 2080, and even the A1T scenario that envisages a change to renewable and nuclear energy sources starts to decline from 2090. The political consequences in a world based on a strong growth philosophy entering constant economic decline are unimaginable – the current global financial crisis is a pinprick in comparison.

Appendix 3 contains many warnings that worst cases have tended to become mainstream, from Weitzman's "fat tail" distribution giving more weight to extreme outcomes (2009), and Garnaut's (2008) observation that some severe and damaging shocks that were once near the edges of the distributions are now near the middle, to the unequivocal warning by Richardson et al. (2009) at the Copenhagen scientists' meeting in March 2009.

One feature of the A1 scenarios may be that the laissez-faire economic policies that allegedly led the world into trouble in 2008 (see Appendix 5) will be perpetuated, causing continued corporate and financial sector growth fixation and predatory behavior. The final question is whether the strong faith in technological solutions underpinning these scenarios would be justified. At best, this may be a race against time: will the technologies be able to make all countries take a quantum leap, with the right mix to assist the weaker nations as well as the right mix to protect against the worst excesses of climate change?

The risks of following such a course are great. The one possible positive factor is the global population projection: while inevitably going to nine billion by 2050 it will then decline to seven billion by the end of the century, with virtually all countries eventually contributing to the decline since we have already witnessed an general decline in fertility rates (children per woman): The world average fell from 4.47 in 1970-75 to 2.55 in 2005-10 and is expected to decline further to 2.02 in 2045-50 according to the United Nations medium 2006 projection. In 1970-75, 143 of 195 countries (73%) showed a total fertility rate of 3 or more. This had fallen to 71 countries (36%) by 2005-10 and is projected to fall to only seven countries (less than 4%) by 2045-50.

### 7.2.4 LINKING THE PRESENT TO THE STORYLINE

The A1 scenarios, especially the fossil-intensive variant, have been seen as closest to the "business-as-usual" scenario which economists and scientists alike denounce as a disastrous long-term path. Other scenarios, however, are equally likely and possible, at least in principle (B2 now seems more outdated than the other scenarios, and would be more favorably viewed today). Whatever is made out of the slowness and setbacks of the current political process, environmental policies and concerns for climate change have gained prominence over the past several years, significant business opportunities have emerged, and the foundation has been strengthened for a plausible global scenario of the "B1" variety. It is also possible that the trend towards globalization of the past few decades – never fully accepted as the only possible world philosophy despite past advocacy from international organizations – may be replaced by a more regionalized world, as in A2 and B2.

That said, the path towards a steady-state A1 type scenario is relatively close to "business-as-usual", even uncomfortably so. While the realization of this might act as a wake-up call which could cause a more decisive switch to an environmentally protective B1 alternative, the rules of scenario planning for now are that each is played out without mitigation.

An introduction to the A1 scenario story written for this project in early 2009 has proved substantially correct and can now be the lead-in to all four scenario stories:

*Despite increasing attention to climate change in the lead-up to the Conference of the Parties in Copenhagen in December 2009 (COP-15), climate change deniers and enormous vested business interests prevail. The financial crisis deprives the world of fresh American leadership against climate change, and resistance from Congress cripples the Administration's moves to address the issue of climate change in matters such as effective carbon cap-and-trade schemes and assistance to developing countries to reduce the rise in greenhouse gas emissions and taking a bold initiative in Copenhagen in December.*

The main casualty, not anticipated in early 2009, may have been universal cap-and-trade schemes. Apart from the reference in Section 7.2.2 to the work of Glyn Prins and his colleagues (2009, 2010), this is discussed in Appendix 5 under the heading of "lessons for climate change policy from recent events," which suggests that more acceptable schemes may prove to be directed more specifically towards individual industries, either in the form of taxes or other penalties, or in the form of incentives to improve energy efficiencies. Partial cap-and-trade schemes, for instance directed towards the power generating industry, have also been proposed. Naturally, enormous resistance against any scheme is likely to eventuate, but probably not as vehement as the resistance that demolished the universal cap-and-trade proposal in 2009. From then on, A1 may develop along lines like the following:

1. Following the inconclusive and non-binding results in Copenhagen, subsequent COP-meetings in 2010 and 2011 fail to produce firm results, whether along the lines of cap-and-trade or other possible solutions.
2. The US mid-term elections in November 2010 do not favor climate change reform.
3. The US economy recovers in 2011 with most of the business sector intact including the big energy corporations and an unreformed financial sector in which the leading survivors have gained, not lost, ability to control the market and influence public opinion and economic policy.
4. Despite the drama of the most publicized environmentally related event in 2010, the Deepwater Horizon oil spill off the coast of Louisiana recognized as the worst such incident ever, the political response is largely to shrug it off, and successfully sideline the national commission set up to investigate the matter. "Business-as-usual" prevails over environmental concern.
5. The reluctance of the western world to undertake serious reform results in China and India, in particular, abandoning some of their initial attempts to cooperate globally. Promising initiatives such as US-Chinese cooperation on solar technology drag on but without firm commitment from participating countries. The focus swings back to coal. On food security, which is a growing concern, the emphasis is also on "big technology." Genetic engineering plays a large role in developing drought- and heat-resistant crops, which may be seen as beneficial for global food supplies but is dominated by big corporations to the virtual exclusion of other stakeholder groups.

6. The US economy is generally highly progressive, and as the decade moves on and the economy resumes full speed ahead, the impact of a strengthening education policy starts to benefit the energy sector, with a bias towards big-ticket items like fossil-fueled power plants rather than renewables. Other first-world nations also resume their growth; China, India, Brazil and others benefit from the technologically interconnected global pattern and continue their strong economic growth. Carbon capture and storage receives strong political support promoted by the coal lobbies, but the technology, as expected, proves difficult to develop economically.
7. During the late 2010s, scenario planners become aware of a 'fork in the road ahead', which can lead to two different fossil-energy paths. No one can say which fork will be taken in a future that remains essentially unknown and unpredictable. But according to these scenario planners, one path could, in the fullness of time, prove fatal for our global civilization, as we have come to know it, while the other might prove more viable though still full of major uncertainties and great risks.
8. "Fork one" encompasses the exploitation of all possible fossil fuel resources, including marginal resources such as shale oil, deep sea and polar sources, plus natural gas and the still abundant coal reserves. Scenario planners keep the name of this path as A1FI, originally given to the fossil-fuel intensive scenario devised for the IPCC Third Assessment Report in 2001. It seeks to perpetuate the fossil-fuel world of the past century, and the globalization that snowballed in the 1990s and early 2000s.
9. In "fork two", it is realized that conventional petroleum resources are peaking and likely to run out within a few decades, and that the environment needs to be brought back from the backburner (where it has sat since the end of the Copenhagen conference and subsequent COP-meetings with much talk and few commitments). The plan is to use the formidable technological capacity that is emerging internationally to develop a range of economically viable energy sources, both through renewables and through carbon sequestration designed to make fossil fuel use environmentally safe. Renewables win in the shorter term on technical and economic feasibility. Nuclear fission – an existing technology favored by many countries – also play an important role despite its long lead time (fusion remains a distant dream at least until the last quarter of the 21st century). This scenario retains the name A1B, balancing fossil with renewable and nuclear technologies. Some planners see fossil fuels being phased out over the century (the A1T variant), but that is a lengthy process.
10. Enter the scenario IPCC described from, say, 2025. The main scenario story is A1B, but the variants are specifically analyzed in Appendix 4 to estimate limits to economic growth as the globe warms.

### 7.2.5 GLOBAL PATH TO 2100 AND BEYOND

Table 7.3, for each of the three scenario variants of A1, shows three different estimates of world GDP in the 21st century, based on the projections of the IPCC reports but then asking whether the world can continue to grow strongly under conditions of strong global warming, as the IPCC projections assume.

**Table 7.3: Unadjusted and adjusted World Product: A1**

| | $ trillion at 1990 values | | | Proportion of unadjusted | | Projection |
|---|---|---|---|---|---|---|
| | Unadjusted | "Most likely" | "Worst case" | "Most likely" | "Worst case" | $ trillion (1990) |
| **Marker scenario A1B** | | | | | | |
| 1990 | 20.9 | 20.9 | 20.9 | 100% | 100% | 20.9 |
| 2010 | 37.9 | 37.9 | 37.9 | 100% | 100% | 37.9 |
| 2035 | 108.1 | 108.1 | 107.8 | 100% | 100% | 108.0 |
| 2050 | 181.3 | 181.3 | 172.3 | 100% | 95% | 176.8 |
| 2075 | 341.1 | 321.3 | 256.6 | 94% | 75% | 289.0 |
| 2100 | 528.5 | 446.6 | 201.9 | 85% | 38% | 324.3 |
| **Scenario A1FI** | | | | | | |
| 1990 | 20.7 | 20.7 | 20.7 | 100% | 100% | 20.7 |
| 2010 | 38.1 | 38.1 | 38.1 | 100% | 100% | 38.1 |
| 2035 | 98.6 | 98.6 | 94.9 | 100% | 96% | 96.8 |
| 2050 | 164.0 | 159.5 | 138.6 | 97% | 85% | 149.1 |
| 2075 | 329.5 | 268.5 | 103.7 | 81% | 31% | 186.1 |
| 2100 | 525.0 | 262.5 | 40.9 | 50% | 8% | 151.7 |
| **Scenario A1T** | | | | | | |
| 1990 | 20.9 | 20.9 | 20.9 | 100% | 100% | 20.9 |
| 2010 | 36.8 | 36.8 | 36.8 | 100% | 100% | 36.8 |
| 2035 | 113.4 | 113.4 | 113.4 | 100% | 100% | 113.4 |
| 2050 | 187.1 | 187.1 | 183.6 | 100% | 98% | 185.4 |
| 2075 | 358.1 | 348.8 | 301.6 | 97% | 84% | 325.2 |
| 2100 | 555.0 | 497.5 | 309.9 | 90% | 56% | 403.7 |

Source: See Appendix 4

The base year is 2010, from which we have a “near-term” 25-year outlook for 2035, and two intermediate years (2050 and 2075) on the way to the “long-term” outlook for 2100. The first column is the unadjusted projection from the SRES report (Nakicenovic and Swart 2000), showing continued growth for all three scenario variants from a level of about $38 trillion in 2010 to $530-550 trillion in 2100 (the variation is due to the Third Assessment teams in 2001 choosing slightly different versions of the A1 scenario family as the official scenarios). The values are in 1990 dollars. The actual global GDP in 2008 was $60.6 trillion according to the World Bank, up from $21.8 trillion in 1990 (slightly above the base year figures in Table 7.3). The projections could be converted to 2010 values using a factor of 1.6, but it is the trends rather than the levels that are of most interest.

The next two columns of Table 7.3 show adjustments based on the assumptions made on the basis of global warming trends in Appendix 4 taken from IPCC’s Fourth Assessment Report. With most data being available on average temperatures, these become the proxy for other symptoms of climate change including rising sea levels, more violent storms, and ocean acidification. Further work and more sophisticated modeling would be needed to check the relationships between temperatures and the other variables.

The assumptions are illustrated in Appendix 4, Figure 3, suggesting that GDP starts to get affected when global average temperatures reach 1.5$^{O}$C above pre-industrial levels, which is about twice the increase already recorded, with more increases already in the pipeline due to delays in the carbon cycle and other factors. It was noted in Section 2.2 that GDP is assumed to be reduced by 5% at +2$^{O}$C, 50% at +4$^{O}$C, and 90% at +6$^{O}$C. Appendix 4 contains sensitivity analysis which largely supports the base case shown here.

The "most likely" middle-of-the-road A1 scenario (A1B), adjusted for expected global temperature increases, shows continued growth to a level 15% below the unadjusted IPCC scenario, but in the worst case deviations from the unadjusted projection start before 2050 and there is a drop of over 20% in the global GDP in the last quarter of the century, to a level of only 38% of the unadjusted projection. The right-hand column of Table 7.3 (midway between the "most likely" and "worst" cases as explained in Section 6.6) suggests continuous growth through the century but at rapidly declining rates, from 4.3% per annum between 2010 and 2035 to 3.3% pa from 2035 to 2050 and 2.0% pa 2050-75, to only 0.5% pa in the final quarter-century to 2100.

The most likely path for the fossil-intensive variant, A1FI, starts to fall below the unadjusted projection before 2050 and declines from about 2075 to a level exactly half of the unadjusted projection for 2100. In the worst case, A1FI falls short of the unadjusted path from before 2035, reaches its peak around 2050 when it is already 15% below the unadjusted projection, and drops to only 8% of that projection in 2100, when the assumed global temperature increase is 6.4% above pre-industrial levels. The worst case in more recent projections has a higher temperature change, but this illustration must suffice here.

If the global economic growth scenario includes replacing fossil fuels with renewables, the most likely case is strong and continued growth to almost $500 trillion by 2100, 90% of the base projection. However, the worst case sees virtual cessation of economic growth from 2075 based on the IPCC's own assessment of global warming – in fact, the more detailed projections in Appendix 4 show actual decline in the last decade of the century.

In the absence of mitigating action, the prospects from the second half of the 21$^{st}$ century look risky indeed. Looking beyond 2100, this does not augur well for what might happen in the next century, with the trend accelerating towards higher temperatures, and there is always a risk that the scenario will tilt further towards the worst case during this century, causing the world GDP to decline from, say, 2075. If left to run their course, the A1 scenarios all lead to utterly unpredictable, chaotic situations in the 22$^{nd}$ century – probably collapse under A1FI and the best chance for our civilizations to survive under A1T.

Some projections may suggest that there will be time to adjust even going down a high-growth fossil fuel path – after all, even in the worst case growth continues into the middle of the century. This is unfortunately not so. At the lower growth projections, $CO_2$ emissions would be reduced compared with the unadjusted IPCC trajectories, but the lower growth has itself been caused by higher temperatures, so the damage has already been done.

This section has shown is that the IPCC rates of global economic growth won't happen if our assumptions about the world's inability to keep up the assumed economic growth in conditions of rapid warming are correct. It may be argued, of course, that with strong economic growth, a much richer world population would be able to shield itself – all nine billion of us by 2050 – in suitable housing and other environments. This stretches the credibility; at least it suggests that a mammoth part of the world's additional resources would be needed as protection against excessive temperatures, and the benefits will differ enormously between rich and poor countries, disadvantaging the latter.

In conclusion, even the best case A1 scenario is likely to lead to temperature increases above +2$^{O}$C; in the worst case, even A1T despite its switch to renewable energy sources shows temperature changes approaching +4$^{O}$C by 2100. Worst cases, as stressed elsewhere in this report, have had an unfortunate tendency to move from the "unlikely" end of the probability distribution closer towards its center (Garnaut 2008), or in Weitzman's estimation (2009) a larger proportion of "unlikely" events have become more likely – the tails of the distribution have become "fatter".

### 7.2.6 THE UNITED STATES IN AN A1 CONTEXT

In many ways, the global scenario is reflected, and to a considerable extent led, by the United States, though the extent would vary with the scenario. Rather than spelling out the obvious consequences in terms of energy policy, we have chosen to present the additional perspective based on Murphy (2007). The addendum at the end of Appendix 3 outlines three scenario stories of his based on "fast-forwarding" some worrying current trends.

The first scenario concentrates strongly on homeland defense, the second on disintegration of national power as large cities all over the world develop into powerful city-states with their own agendas and a great potential for conflict, and the third on the uninterrupted rise of private corporate power, with fifty corporations already among the 100 largest "economies" in the world. All three are "A-type" economy-dominated scenarios, and the last is most readily compatible with A1. The first two scenarios might develop as part of the regionalized economic scenario A2, complete with rising conflict as described in Section 7.4. However, America's interest in policing regions of strategic economic importance is also relevant in the A1 scenarios to protect its global hegemony.

Murphy's antidote against these unfavorable scenarios is his "hundred-year workout plan" (Section 7.1.4). It is unlikely to be followed at least in the balanced-energy and fossil-intensive variants of A1 because these futures tend to follow past trends. It was suggested in the previous paragraph that the role of the United States as self-appointed global policeman would cause it to continue a strong military presence to maintain influence and control over strategically important areas, such as oil-producing regions. A1 could also see continued rise in corporate power on a truly global scale, undisputed lords of the world's water, food, information, health, energy, transportation, software, music, security, and violence, as listed by Murphy (2007, p 200).

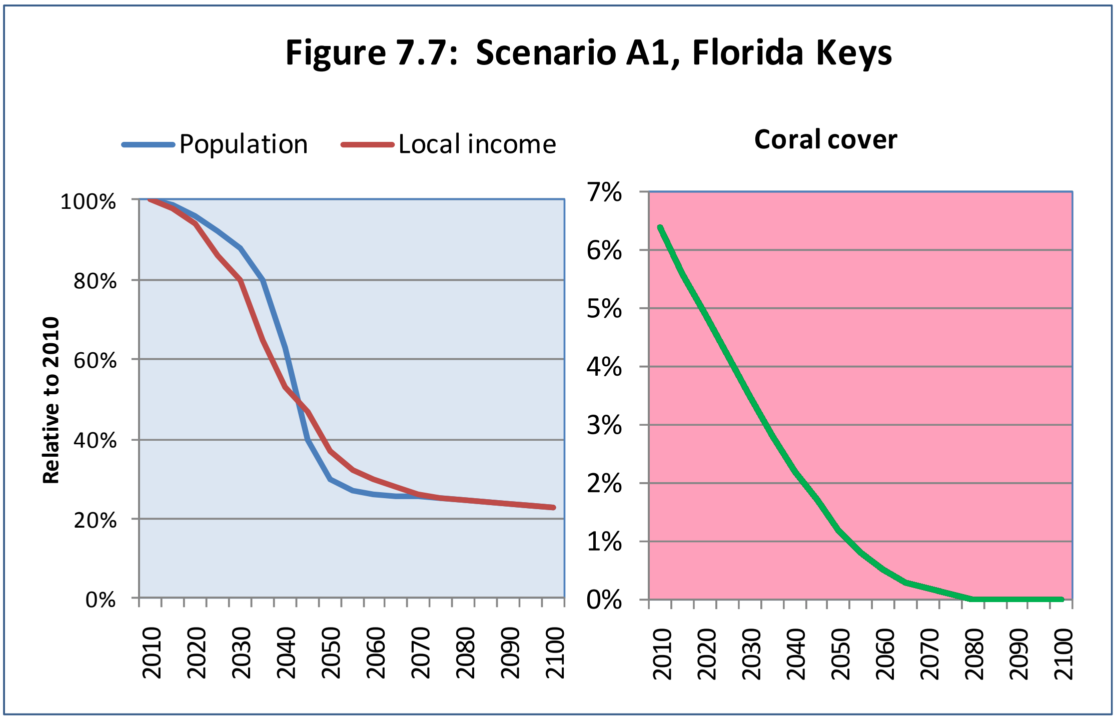
Whether or not the world continues to be dominated by America, such a perspective would become truly frightening when or if the world economy starts to run into growth bottlenecks as suggested in Appendix 4. Macroeconomic policy would also fly in the face of the reforms suggested by the economics of climate change and how to deal with unbridled speculative activities (Appendix 5).

As far as the limits to growth due to climate change and global warming are concerned, the United States with its great wealth may be able to protect most of its citizens, though maybe not its least privileged groups, in conditions of growing discomfort, but much of the developing world couldn't, and if and when global GDP begins to fall in the worst-case fossil-intensive scenario, the US economy will suffer badly too. Furthermore, unfavorable natural conditions will include increasing droughts, dust bowls, forest fires, damage from increased hurricane and other violent weather activity, and sea-level rise (where the whole of southern Florida and other coastal parts of the State are particularly vulnerable).

### 7.2.7 Zooming in on the Florida Keys

**Table 7.4: Global and local projections for Scenario A1**

| Scenario A1 | 2010 | 2035 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Global temperature increase (°C) | 0.8 | 2.0 | 3.0 | 3.5 | 4.0 |
| Global sea-level rise (cm) | - | 12 | 37 | 57 | 80 |
| Global ocean acidification (pH) | 8.1 | 8.0 | 7.9 | 7.8 | 7.7 |
| Annual world GDP change | 3.0% | 4.3% | 3.3% | 2.0% | 0.5% |
| Keys population | 72,000 | 57,600 | 21,600 | 18,000 | 16,600 |
| Population relative to 2010 | 100% | 80% | 30% | 25% | 23% |
| Keys coral cover | 6.4% | 2.8% | 1.2% | 0.1% | 0.0% |
| Coral cover relative to 2010 | 100% | 44% | 19% | 2% | 0% |
| Keys area remaining | 100% | 80% | 30% | 25% | 23% |
| Value of Keys area remaining | 100% | 86% | 56% | 49% | 45% |
| Keys income relative to 2010 | 100% | 65% | 37% | 25% | 23% |




The high global economic growth suggested by Table 7.4 might initially have been thought to benefit the Florida Keys in terms of income, but this would be rapidly dissipated by the physical reality of sea-level rise. The population is assumed to fall in proportion to the loss of land, with carrying capacity stretched to the limits, and the remaining wealth will probably be increasingly absorbed elsewhere.

The most striking result of Chris Bergh's research (2009), analyzed in Section 7.1.5, is the dramatic land loss between 2035 and 2050 in the A1 scenario as the global temperature increases from 2$^{O}$C to 3$^{O}$C above pre-industrial levels, and the global sea level rises from 12 to 37 cm above the base level. This is estimated to cause the remaining land area in the Keys to decline from 80% to 30% of currently existing levels. Bergh (2009) is on record for projecting 38% land loss at the *most optimistic* 18 cm IPCC sea-level rise. At the *most likely* IPCC estimate of 28 cm global sea-level rise, Table 7.1 suggested that 55% of the Keys would be inundated.

The Keys population is assumed to be directly correlated with the remaining land area, which means a reduction from 72,000 persons in 2010 to 57,600 in 2035 and 21,600 in 2050, after which the decline becomes less dramatic (Table 7.4). This development could not have been estimated without Chris Bergh's research into the connection between the topography of the Keys and the projected sea level. Intuitively, the population decline would have been expected to be much more gradual than Figure 7.7 shows.

The model proposed for the connection between remaining land values and local incomes in the Keys has two components: the proportion of total value remaining according to Bergh (2009), coral cover, used as the only proxy of future marine-based tourism potential we know. Giving these two indicators equal weight results in a timeline not dissimilar from the population trend: strong decline, especially between 2035 and 2050, and then less of a decline. Both indicators end up in 2100 just above 20% of the 2010 level. The loss of coral cover indicates the loss of marine-based tourism as it is known today, and the value of the remaining assets will increasingly benefit external rather than local interests.

The economic analysis of the results of the visitor survey conducted under NOAA auspices for 2007-08 (Section 6.3) showed total spending by cruise-ship passengers increasing strongly despite a fall in per capita spending based in Key West (Tables 6.22 and 6.25), and spending by overnight visitors also increased compared with 1995-96 (Table 6.25). These factors were important although the total increase between the two survey dates (Table 6.26) was largely due to more people owning or leasing condominiums and time-share accommodation, but having their residence elsewhere. The continued role of cruise ships and expatriate people renting or owning premises in the Keys would help explain how an increasing share of the total value of Keys assets would be owned outside the Keys.

The coral cover is estimated to be down to 1.2% by 2050 and to disappear by 2075, from the 6.4% estimated for 2010. Temperatures will increase to very unpleasant levels at least from 2050, requiring progressively better (and dearer) building insulation. The oceans will become progressively more acid. A decline in pH to 7.7 would have disastrous consequences not only for coral reefs but for a broad range of other calcareous organisms in the Southern Ocean in particular. There is also evidence that an acidified ocean affects the ability of fish to navigate (Appendix 3, referring to Raven et al. 2005, and Munday et al. 2009). In the Keys, it all points to continuing decline of marine-based tourism.

The population of the Florida Keys, already declining with an increasing number of well-to-do absentee owners of condominiums and similar types of accommodation, will fall to a low projected level of 16,600, compatible with the inundation (Figure 7.4). We don't know whether they will be rich, and maybe even fewer in number. The economic mainstay, tourism, will be progressively affected, though the number of cruise-ship passengers may revive in a richer world in the next 25 years, benefiting Key West (to the extent that the sea-level rise is controlled there) and continuing the trend towards a higher share of land-based activities found in the NOAA visitor surveys. Sailing and boating may continue but based on other facilities as there will be little infrastructure in the Keys after 2050 to support these activities.

In summary, even the "balanced" fossil fuel/renewable growth scenario will leave the Keys devastated. Furthermore, there is no light at the end of the tunnel in the 22$^{nd}$ century if the global Scenario A1B is allowed to run its course. By then, not just the Keys but the whole A1 world is projected to go into reverse.

## 7.3 B1: Global environmental focus

### 7.3.1 The IPCC storyline

The central elements of the B1 future are a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development. Heightened environmental consciousness might be brought about by clear evidence that impacts of natural resource use, such as deforestation, soil depletion, over-fishing, and global and regional pollution, pose a serious threat to the continuation of human life on Earth. In the B1 storyline, governments, businesses, the media, and the public pay increased attention to the environmental and social aspects of development. Technological change plays an important role. At the same time, however, the storyline does not include any climate policies, to reflect the SRES terms of reference. Nevertheless, such a possible future cannot be ruled out.

A "Conventional Worlds – Policy Reform" scenario from 1997 is a good example of such a future, although it includes climate policies. Another scenario from 1995 describes a reaction to early decades of crime and chaos, in which community values triumph over individualist ones and lead to resource-friendly lifestyles based on clean and light technologies. This scenario includes a voluntary embrace of cohesion, cooperation, and reduced consumption, backed by legislation and even corporate policies. In a normative scenario from 1997, the world achieves an environmentally sustainable economy by 2050, primarily through education to develop human potential. In a scenario from 1992, economic equilibrium and innovation lead to sustainable development. The "ecologically driven" scenarios by WEC (1993) and IIASA-WEC (1998) with accelerated efficiency improvements in resource use share several of the characteristics of the B1 type of future, as does an egalitarian utopia scenario from 1997.

Many additional scenarios in the literature could be seen as examples of this family, but may describe the changes as more fundamental than those of B1. One scenario stresses the role of global technological innovation in addition to enlightened corporate actions, government policies, and empowerment of local groups. In another, from the Millennium Institute, resources are shared more equitably to the benefit of all and the greater safety of humanity. Other scenarios from 1989 and 1998 examine sustainable futures.

Economic development in B1 is balanced, and efforts to achieve equitable income distribution are effective. As in A1, the B1 storyline describes a fast-changing and convergent world, but the priorities differ. Whereas the A1 world invests its gains from increased productivity and know-how primarily in further economic growth, the B1 world invests a large part of its gains in improved efficiency of resource use ("dematerialization"), equity, social institutions, and environmental protection.

A strong welfare net prevents social exclusion on the basis of poverty. However, counter-currents may develop and in some places people may not conform to the main social and environmental intentions of the mainstream in this scenario family. Massive income redistribution and presumably high taxation levels may adversely affect the economic efficiency and functioning of world markets.

Particular effort is devoted to increases in resource efficiency to achieve the goals stated above. Incentive systems, combined with advances in international institutions, permit the rapid diffusion of cleaner technology. To this end, R&D is also enhanced, together with education and the capacity building for clean and equitable development. Organizational measures are adopted to reduce material wastage by maximizing reuse and recycling. The combination of technical and organizational change yields high levels of material and energy saving, as well as reductions in pollution. Labor productivity also improves as a by-product of these efforts. Alternative scenarios considered within the B1 family include different rates of GDP growth and dematerialization (e.g., decline in energy and material intensities).

The demographic transition to low mortality and fertility occurs at the same rate as in A1, but for different reasons as it is motivated partly by social and environmental concerns. Global population reaches nine billion by 2050 and declines to about seven billion by 2100. This is a world with high levels of economic activity (a global GDP of around US$350 trillion by 2100) and significant and deliberate progress toward international and national income equality. Global income per capita in 2050 averages US$13,000, one-third lower than in A1. A higher proportion of this income is spent on services rather than on material goods, and on quality rather than quantity, because the emphasis on material goods is less and also resource prices are increased by environmental taxation.

The B1 storyline sees a relatively smooth transition to alternative energy systems as conventional oil and gas resources decline. There is extensive use of conventional and unconventional gas as the cleanest fossil resource during the transition, but the major push is toward post-fossil technologies, driven in large part by environmental concerns.

Given the high environmental consciousness and institutional effectiveness in the B1 storyline, environmental quality is high, as most potentially negative environmental aspects of rapid development are anticipated and effectively dealt with locally, nationally, and internationally. For example, trans-boundary air pollution (acid rain) is basically eliminated in the long term. Land use is managed carefully to counteract the impacts of activities potentially damaging to the environment. Cities are compact and designed for public and non-motorized transport, with suburban developments tightly controlled. Strong incentives for low-input, low-impact agriculture, along with maintenance of large areas of wilderness, contribute to high food prices with much lower levels of meat consumption than those in A1. These proactive local and regional environmental measures and policies also lead to relatively low greenhouse gas emissions, even in the absence of explicit interventions to mitigate climate change.

### 7.3.2 WOULD THIS SCENARIO STORY HAVE BEEN WRITTEN DIFFERENTLY IN 2010?

The philosophy has not changed since the B1 scenario story was written. The first two sentences in IPCC's description set the stage – note the "and social" which is often overlooked but is a natural ally of environmental consciousness (so is "cultural"). That community values prevail over individualist ones is natural, given the general philosophy behind the B1 scenario. The use of the word "utopian" describing a scenario written in 1997 marks a step towards the way environmentally friendly policies are now perceived. Today, with an even bigger need to combat climate change, this scenario provides the best path towards avoiding its worst effects, and while it may be resisted there is no longer anything utopian about such a policy.

The main caveat is that the projected greenhouse gas levels are much higher than is becoming acceptable if the world average temperature is to stay within $+2^{O}C$ of pre-industrial levels. Interestingly, the emphasis on technological change in the terms used in Appendix 6 is on energy efficiency and – possibly to a slightly lesser extent – land use. The transition to renewable technologies is seen as essential but told in two sentences, without specification.

The main new features that should be added to the story told today concerns the greater urgency to bring down greenhouse gas emissions with all possible acceptable technologies: a rapid switch to renewables, a probable role for nuclear technologies, increased emphasis on energy efficiencies, a higher profile for agricultural land use and forest management, and the use and protection of oceanic sinks. It is encouraging that genuine innovative activities are beginning to spread across a larger number of nations (Appendix 6), but it is also essential to keep diffusing the appropriate technologies to all countries including the poorest and least developed ones.

### 7.3.3 CURRENT PHYSICAL, ECONOMIC AND TECHNOLOGICAL INFLUENCES

An environmentally sensitive scenario with a global perspective is most likely to lead to a minimization of average global temperatures to $2^{O}C$, while achieving a reduction to <350 ppm atmospheric $CO_2$. The B1 scenario according to the Fourth Assessment Report has a "most likely" average temperature increase of $1.8^{O}C$, and a worst-case rise of $2.9^{O}C$, which is well into the risky range according to recent assessments. The projected level of atmospheric $CO_2$ in 2100 is 545 ppm, which is too high for current comfort but the lowest of the Fourth Assessment Report scenarios (Appendix 3).

B1 is the only scenario showing continuing growth in the worst case when constraints are put into the model to reflect reactions of economic growth to warming. All other worst-case scenarios show a change to economic decline sometime in the second half of the 21st century (Appendix 4, Figure 5).

Economic policy may be assumed to change from the past lack of sensitivity to the economics of climate change, and to curb the excesses of financial sector speculation that caused the current economic downturn. It is also plausible that there will be a stronger tendency for economics to cross-fertilize with other social and physical sciences to the benefit of all, as discussed under the general heading of complexity theory in Appendix 5. Climate policies are likely to favor incentives, whether to promote renewable technologies or energy efficiency. Carbon taxes rather than emissions trading schemes, and specific industry policies, will probably be the norm. There will be a strong thrust toward assisting less developed countries to adopt renewable energy technologies and efficient use of energy, aimed at small communities as well as major technological projects.

Technology will be balanced, with the development of renewable energies on a wide range of scales (some will be economically feasible at mega-level, but many in smaller units). The technologies include wind, solar, geothermal and others, already at an advanced stage of development and capable of either filling “wedges” in the Pacala/Socolow (2004) sense of contributing to the global need for alternative energy sources, or to fit local community needs (the sum total of which might itself fill “wedges”). Technological progress will also be strongly geared towards energy efficiencies and towards developing and protecting forestry, agricultural and “blue carbon” sinks – the latter directed towards the worldwide protection of mangroves, seagrasses, salt marshes, coastal wetlands and estuaries which are essential for capturing $CO_2$ for long-term storage in the oceans (Nellemann et al. 2009).

An important part of the technological thrust, while differentiated in scale, will be towards assisting less developed countries at local level. This includes assistance to improve food security through better infrastructure, including roads and storage facilities, backed by thoughtfully administered advice and training to improve local management skills. Genetically engineered crops and other products will be promoted after extensive ecological safety tests, based on the strong advances in biotechnology reported in Appendix 6. Other agricultural technologies aimed at attaining better biodiversity as well as food security will maintain a strong position, along the lines of Shiva (2005) and others.

### 7.3.4 LINKING THE PRESENT TO THE STORYLINE

Despite the disappointment of the conference failing to reach binding agreement, the "Copenhagen Accord" presented on the last day of the COP-15 meeting in December 2009 had sufficient positive content to preserve a spirit of cooperation and sense of urgency for the two subsequent annual meetings to achieve commitment from both the developed and the developing worlds. The Bali Action Plan or Bali “Road Map” of 2007 had already established a shared long-term vision and four “building blocks” of increased mitigation of greenhouse gases, adaptation to climate change, technology transfer and development, and financing (the latter especially important in securing assistance to less developed countries).

Efforts to include prevention of deforestation in the Clean Development Mechanism were also met with approval in principle. This was important not only for the direct recognition, but also because of the links with agriculturally based technologies in the effort to improve the planet’s carbon sinks – too long underestimated in the fight to control greenhouse gases.

While the Copenhagen meeting failed to quantify the essential elements of a fair and effective deal on climate change, the continued negotiations binding the annual COP meetings together were intensified, and a binding agreement was signed by all parties at the 2011 meeting. Ratification by a sufficient number of member nations followed in time to provide a effective successor to the Kyoto Agreement.

In May 2010, following only a month after President Obama’s decision to allow exploration for oil along the Atlantic coast, in the Mexican Gulf, and north of Alaska, the Deepwater

Horizon well, an unconventional petroleum source in the Gulf, caused the worst oil spill disaster in American history. The President took strong action as it became clear that the event was indeed catastrophic, and assumed full leadership. He declared on June 3 (*Washington Post* video):

"What kind of energy future can ensure our long-term prospects? The catastrophe unfolding in the Gulf right now may prove to be a result of human error or a corporation taking advantage of shortcuts to compromise safety, or a combination of both. I have launched a national commission so that the American people will have answers on exactly what happened. We have to acknowledge the inherent risks of drilling four miles beneath the surface of the earth; these risks are bound to increase the harder oil extraction becomes. Once this is acknowledged, that America runs fully on fossil fuels should not be the vision we have for our children and grandchildren."

The US Administration meanwhile abandoned its efforts to put through a universal cap-and-trade bill in favor of a version of what was originally known as the Kerry-Lieberman-Graham proposal which these senators had been asked to put in train urgently during the first quarter of 2010. The mid-term elections intervened, however, and the first climate bill was passed in 2011, switching the emphasis from the overall penalty approach of cap-and-trade to incentives aimed at individual industries, coupled with control of polluters. A partial cap-and-trade scheme was imposed on the power generation industry, though considerable concessions were needed to reduce the sense of injustice that the industry claimed to feel.

The 2011 climate bill succeeded in making the unconventional fossil fuel sources brought into play in the A1 scenario unrealistic competitors, despite the prospect of conventional oil resources running out. Coal suffered because the cost of mandatory CCS technology for new plants was not coming down as fast as hoped, a problem even more serious when retrofitting existing plants. All these factors caused the dynamics of the energy sector to change more rapidly towards renewables in the second half of the 2010s.

The Deepwater Horizon spill, with its damage to the most important wetlands in the nation, on the coast of Louisiana, and threatening the ecosystems of the Florida Keys and into the wider Caribbean (though this appears to have been averted), helped returning public opinion towards environmental concerns. Meanwhile, evidence of climate change became more apparent, with record temperatures, more frequent hurricanes and extreme monsoonal events, and convincing evidence of sea-level rise. The widespread effect of ocean acidification on calcareous marine organisms everywhere raised the public consciousness of this factor to new levels. All this helped an economically viable B1 scenario come into play naturally from the mid 2020s.

### 7.3.5 Global path to 2100 and beyond

The unadjusted path from the IPCC's Third Assessment Report shows growth to almost nine times the current world GDP (Table 7.5). Assuming these rates are indeed achievable, they will be practically reached in the most likely case of global warming rates, and even in the worst B1 case world GDP may still grow to over 80% of the unadjusted case at the end of the century.

This is clearly the best result of any of the scenarios, but although the assumed level of atmospheric $CO_2$ is the lowest according to Table 1 (in Appendix 4), it is still about 200 ppm higher than what appears to be the emerging "safe" standard of 350 ppm or less.

**Table 7.5: Unadjusted and adjusted World Product: B1**

| | $ trillion at 1990 values | | | Proportion of unadjusted | | Projection |
|---|---|---|---|---|---|---|
| | Unadjusted | "Most likely" | "Worst case" | "Most likely" | "Worst case" | $ trillion (1990) |
| 1990 | 21.0 | 21.0 | 21.0 | 100% | 100% | 21.0 |
| 2010 | 37.3 | 37.3 | 37.3 | 100% | 100% | 37.3 |
| 2035 | 86.9 | 86.9 | 86.9 | 100% | 100% | 86.9 |
| 2050 | 135.6 | 135.6 | 135.6 | 100% | 100% | 135.6 |
| 2075 | 229.1 | 229.1 | 214.6 | 100% | 94% | 221.9 |
| 2100 | 328.4 | 319.3 | 270.4 | 97% | 82% | 294.9 |

Source: See Appendix 4

It was concluded in the discussion of whether the B1 scenario would have been written differently today that for B1 to be adopted as the new model, a concerted effort will be required to marshal the world's resources and cooperation to bring in a widening range of renewable technologies to suit all economic and physical environments, coupled with renewed efforts to maximize energy efficiencies, and to encourage better and more universally applied management of rural and forest resources, and oceanic carbon sinks. In other words, the general B1 philosophy remains, but more is needed.

Such a "super-B1" scenario offers the best hope for the world, and the Florida Keys, over the century and beyond, to help reduce atmospheric $CO_2$ to 350 ppm or below. The global economic growth rate in Table 7.5 might even be achievable across the century, especially if these efforts are augmented with a successful boost to technological innovation and diffusion.

The advent of the Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) is promising in this respect. Its request for information or RFI, dated August 2009, sets a new provocative tone, requiring "*disruptive new, extremely low-cost approaches to manufacturing high quality products*" aimed at "*translating cutting-edge scientific discoveries into transformational new energy technologies.*" See further Appendix 6.

### 7.3.6 The United States in a B1 context

The four items of Murphy's (2007) "hundred-year workout plan" fit in well with the B1 philosophy. Instilling an appreciation of the wider world by being open to immigrants and other outside influences that can help enrich both culture and technology, and supporting governments for their positive contributions, promoting assimilation, and lightening the national military burden are all part of a more open and positive outlook that goes well with a commitment to environmentally friendly policies.

### 7.3.7 Zooming in on the Florida Keys

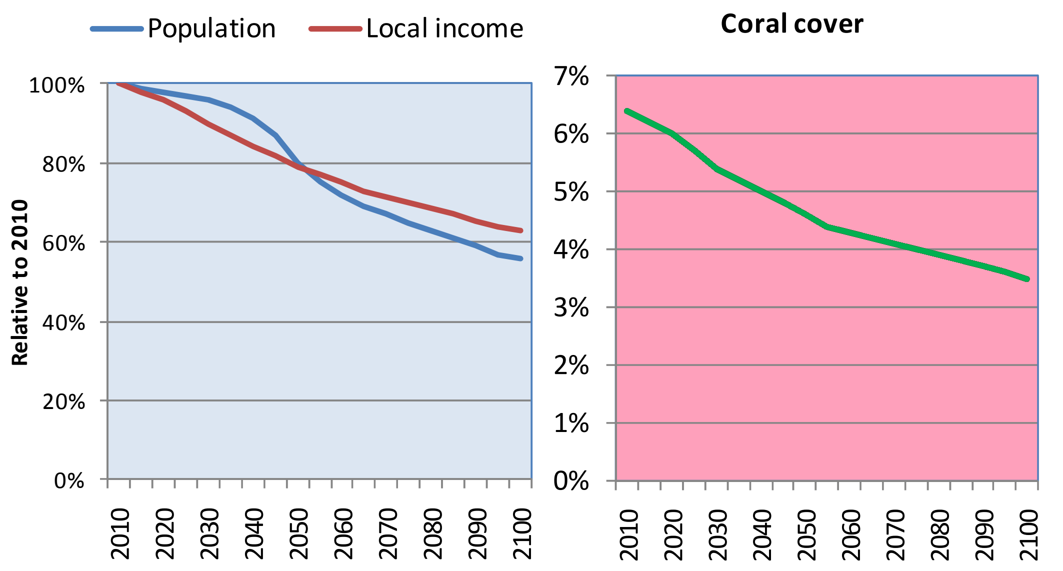
This is clearly the best-case scenario despite the need to strengthen it globally to meet more stringent atmospheric $CO_2$ targets. It is supported in the Keys by the prevailing community

**Table 7.6: Global and local projections for Scenario B1**

| Scenario B1 | 2010 | 2035 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Global temperature increase (°C) | 0.8 | 1.5 | 2.0 | 2.3 | 2.5 |
| Global sea-level rise (cm) | - | 6 | 12 | 17 | 22 |
| Global ocean acidification (pH) | 8.10 | 8.08 | 8.06 | 8.03 | 8.00 |
| Annual world GDP change | 3.0% | 3.4% | 3.0% | 2.0% | 1.1% |
| Keys population | 72,000 | 67,700 | 57,600 | 46,800 | 40,300 |
| Population relative to 2010 | 100% | 94% | 80% | 65% | 56% |
| Keys coral cover | 6.4% | 5.2% | 4.6% | 4.0% | 3.5% |
| Coral cover relative to 2010 | 100% | 81% | 72% | 63% | 55% |
| Keys area remaining | 100% | 94% | 80% | 65% | 56% |
| Value of Keys area remaining | 100% | 95% | 86% | 77% | 71% |
| Keys income relative to 2010 | 100% | 88% | 79% | 70% | 63% |

spirit, with sufficient people being attracted to the lifestyle (including the opportunity to base this on renewable energy sources as is already happening on No Name Key). Young people also respond by more of them staying rather than abandoning the Keys; an issue that came up at the Key Largo scenario-planning workshop in 2008 at the initiative of two young women professionals (Appendix 2, under the heading of "Key Largo: carrying capacity"). Another young woman participant in the same workshop called the Keys potentially "a living laboratory for climate change", which could help attract young people.

**Figure 7.8: Scenario B1, Florida Keys**




Due to good management and local community support, the resilience work is as successful as can possibly be expected, and despite the ocean warming helps allowing most of the coral cover to remain. Sea-level rise will happen but to a relatively limited extent, and work to mitigate and adapt as outlined by Bergh (2009) will prove successful, offsetting some of the impact of physical land loss. Efficient sanctuary management and land-based conservation work is crucial in this scenario.

The projections in Table 7.6 attempt to reflect the best-case IPCC scenario for the Florida Keys. The average global temperature is assumed to rise by 2.5$^{O}$C above pre-industrial levels by the end of the century. The sea-level rise compatible with this scenario is 22 cm, at which level 44% of the Keys would be inundated. This is reflected in the population declining from 72,000 currently to 40,300 in 2100.

Ocean acidification is an external variable, projected to decline from 8.1 to 8.0 (Table 7.6). This is strictly an assumption, and it should be borne in mind that one pH point represents a 30% increase in acidity. Ocean chemistry remains a threat even in the most benign scenario.

The relatively high projected coral cover (3.5% in 2100) is assumed to be consistent with the assumption on acidification, as well as being crucially dependent on the continued resilience policy of the FKNMS and other organizations, and the community's active involvement. Finally, the income estimates in Table 7.6 are made on the assumption that there will be a viable tourist industry with the coral cover in place through the century, backed up by land-based activities associated mainly with Key West. The realism of this is also an assumption, but the City of Key West is beginning to factor sea-level rise into its engineering and construction decisions (Bergh 2009, p 28). It is important, in any case, that Key West remains a crucial part of tourism, and there is cooperation between the historical and nature-based part of the industry.

The graphic results in Figure 7.8 for the main local variables contrast dramatically with the results shown in Figure 7.7 for the growth-orientated A1B scenario.

## 7.4 A2: Regional economic focus

### 7.4.1 The IPCC storyline

The A2 scenario family represents a differentiated world. Compared to the A1 storyline it is characterized by lower trade flows, relatively slow capital stock turnover, and slower technological change. The A2 world "consolidates" into a series of economic regions. Self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between regions are characteristic for this future. Economic growth is uneven and the income gap between now-industrialized and developing parts of the world does not narrow, unlike in the A1 and B1 scenario families.

The A2 world has less international cooperation than the A1 or B1 worlds. People, ideas, and capital are less mobile so that technology diffuses more slowly than in the other scenario families. International disparities in productivity, and hence income per capita, are largely maintained or increased in absolute terms. With the emphasis on family and community life, fertility rates decline relatively slowly, which makes the A2 population the largest among the storylines (15 billion by 2100). Global average per capita income in A2 is low relative to other storylines (especially A1 and B1), reaching about US$7,200 per capita by 2050 and US$16,000 in 2100. By 2100 the global GDP reaches about US$250 trillion.

Technological change in the A2 scenario world is also more heterogeneous than that in A1. It is more rapid than average in some regions and slower in others, as industry adjusts to local resource endowments, culture, and education levels. Regions with abundant energy and mineral resources evolve more resource-intensive economies, while those poor in resources place a very high priority on minimizing import dependence through technological innovation to improve resource efficiency and make use of substitute inputs. The fuel mix in different regions is determined primarily by resource availability. High-income but resource-poor regions shift toward advanced post-fossil technologies (renewables or nuclear), while low-income resource-rich regions generally rely on older fossil technologies. Final energy intensities in A2 decline with a pace of 0.5 to 0.7% per year.

In the A2 world, social and political structures diversify; some regions move toward stronger welfare systems and reduced income inequality, while others move toward "leaner" government and more heterogeneous income distributions. With substantial food requirements, agricultural productivity in the A2 world is one of the main focus areas for innovation and research, development, and deployment (RD&D) efforts, and environmental concerns. Initial high levels of soil erosion and water pollution are eventually eased through the local development of more sustainable high-yield agriculture. Although attention is given to potential local and regional environmental damage, it is not uniform across regions. Global environmental concerns are relatively weak, although attempts are made to bring regional and local pollution under control and to maintain environmental amenities.

As in other SRES storylines, the intention in this storyline is not to imply that the underlying dynamics of A2 are either good or bad. The literature suggests that such a world could have many positive aspects from the current perspective, such as the increasing tendency toward cultural pluralism with mutual acceptance of diversity and fundamental differences. Various scenarios from the literature may be grouped under this scenario family. One example is a society in which most nations protect their threatened cultural identities. Some regions might achieve relative stability while others suffer under civil disorders. In one scenario, economic growth slows down because of a strengthening of protectionist trade blocks. In another, major economic blocs impose standards and regulations on smaller countries. One scenario explores the possibility of regional spheres of influence, whereas another reflects resistance to globalization and liberalization of markets. Noting the tensions that arise as societies adopt western technology without western culture, Samuel Huntington in 1996 suggested that conflicts between civilizations rather than globalizing economies may determine the geopolitical future of the world.

### 7.4.2 WOULD THIS SCENARIO STORY HAVE BEEN WRITTEN DIFFERENTLY IN 2010?

The idea that the world economy might divide into a number of distinct regions is not difficult to imagine; even though the current observed trend is towards globalization the trend is by no means undisputed. There are regions today that could conceivably become isolated and start following their own different social, cultural and economic paths; North America versus Central America, Sub-Saharan Africa in whole or in part, and the Middle East and North Africa may be among such candidates. Smaller but economically powerful regions may emerge as independent international competitors, like the “city-states” and corporate giants mentioned in Section 7.4.6, below.

At the other extreme, China could become a very large isolated region. The World Bank (2009) discusses the country’s environmental fragility: “China’s rapid growth is now a driving force in the global economy and is achieving unprecedented rates of poverty reduction. However, growth is also seriously damaging the natural resource base and generating major environmental liabilities. The country’s environmental problems include land degradation, deteriorating water quality and water scarcity, severe air pollution and declining natural forest cover. These problems threaten the health and prospects of current and future generations and are undermining the sustainability of long-term growth.”

China’s recent economic growth has damaged the environment, but the harm goes further back not just to the foundation of the communist regime, but centuries and millennia before. As the World Bank publication points out, the problems today are manifold. While exacerbated by prosperity, the problems are also more manageable while the economy is growing. China's massive "cleantech" plans, discussed in Appendix 6, may stall as the world fragments into the A2 scenario, especially if the plans become derailed by environmental and economic disasters.

Whichever way the regionalization happens, the impact would differ from region to region. As the scenario story tells us, disturbingly, there is no narrowing between developing and developed countries, technological diffusion slows down, and fertility comes down slowly, resulting in a world population of 15 billion in 2100 (maybe 12 or 13 billion if written today, reflecting recent trends in total fertility rates). Together with the other impacts of climate change, aggravated by a relative lack of attention to environmental matters, A2 seems to be a recipe for growth in the number and severity of regional conflicts.

Agricultural productivity in these circumstances becomes a main focus, with basic food requirements the paramount consideration. Global environmental concerns wane, replaced by a focus on regional issues and local pollution. Hence, climate change becomes a weaker issue, too hard to handle in the global perspective that it needs. Food security remains important, but the global mechanisms governing it are also diminished.

The positive characteristics of this scenario, supporting cultural pluralism and diversity, do not outweigh the global focus that might support cultural diversity in an environmentally and culturally benign scenario, such as B1. Planning for cultural integrity is not explicitly part of B1, but there are reasons to believe that it could be encouraged in that setting. It would actually strengthen the environmentally friendly scenario with its emphasis on preserving biodiversity to nurture vigorously creative cultural and artistic diversity in every nation; the B1 story’s coupling of ecological and social sustainability suggests culture as a natural third leg. A2 is left in the worst possible position compared with alternative worlds without real opportunities even to nurture its own cultural pluralism and diversity on an ongoing basis.

In summary, scenario A2 is exposed, as well as being burdened with environmentally unsustainable population growth. Logically it represents one of the quadrants of the IPCC tree diagram in Figure 7.1, and the concept of a regionalized environmentally ineffectual worst-case scenario is eminently plausible. Some of its basic assumptions would gain from a re-examination, including an updated review of escalating conflict associated with local warfare and international terrorism. It is hard to imagine an A2 scenario written in 2010 that wouldn’t rival the fossil-intensive A1 scenario as the worst case for climate change, with the added disadvantage that it would be more difficult for the poorer and more fragmented A2 world to take adaptive action to avoid the worst effects.

### 7.4.3 CURRENT PHYSICAL, ECONOMIC AND TECHNOLOGICAL INFLUENCES

Scenario A2 is the second-most polluting scenario in the Fourth Assessment Report (Table 1 in Appendix 4) with a most likely temperature rise of $3.4^{O}$C and a worst-case $5.4^{O}$C, and reaching 846 ppm $CO_2$ by 2100. It shows the second-lowest economic growth of all scenarios with economic decline from 2090 in the most likely case and from 2060 in the worst case (Table 5 in Appendix 4). The lowest economic growth in the Fourth Assessment Report, by a marginal amount only, is the regionalized environmental B2 scenario, which if rewritten today would almost certainly show a more benign pattern (see Section 7.5).

Section 7.4.2 suggests that A2 would suffer from an update. The risk of armed conflict as the population multiplies, regions developing at different rates, and food sources struggling to keep up, suggests that the global economy may start going backwards even before the time suggested in Appendix 4 (and summarized below). Any general direction of economic policy would be hard to detect in this regionally decentralized scenario (refer Appendix 5), and technological development is a mixed bag with little cross-fertilization between regions, and relatively weak trends towards renewable technology, energy efficiency, and environmentally sound developments of forestry and land management (refer Appendix 6).

### 7.4.4 LINKING THE PRESENT TO THE STORYLINE

A2 could develop if a double-dipping financial crisis drags on into the mid to late 2010s, effectively crippling international cooperation and causing fragmentation into regional groups such as China succumbing to her internal problems, and the United States taking an increasingly isolationist course to the detriment of her major trading partners, southern neighbors, and global military and diplomatic leadership role. The impact of increasingly lethal terrorism and a feeling of futility about wars in Afghanistan and elsewhere may contribute to a general souring of international cooperation. Conflicts around the world would most likely escalate, especially if food security suffers in Africa and other vulnerable parts of the world.

International organizations, notably the United Nations, the IMF, World Bank and WTO, would lose much of the influence they have built up in a globalized world. The willingness of individual nations to fund the UN and its affiliated organizations has been an issue in the past, with the US falling short of its treaty-obligated contributions for seven years before President Obama pledged to resume the funding on his inauguration in January 2009. A developing trend towards an A2 scenario could well include nations withholding their funding obligations.

Ongoing climate change could cause further damage due to lower environmental protection control, generating added greenhouse gas emissions despite the economic slowdown. An A2 world could certainly develop by the mid 2020s following a severe and protracted economic depression.

### 7.4.5 GLOBAL PATH TO 2100 AND BEYOND

Table 7.7 suggests that this scenario is a worst case, rivaling the fossil-intensive global A1FI variant and with less opportunity for remedial action in a poorer and more fragmented world. Using the model of economic constraints due to global warming in Appendix 4 (Figure

3), the most likely case may keep up with the unadjusted path until the middle of the century but it then falls increasingly behind. The worst case is economic collapse in the second half of the century to a level in 2100 that happens to coincide with the level to which scenario A1FI declines (Appendix 4, Figure 5). It is also at about the same level in 2100 as the estimated world GDP in 2010 at constant 1990 prices, for a global population twice the size of the current one in the original scenario (a level unlikely to be realized as the worst-case A2 scenario plays out).

**Table 7.7: Unadjusted and adjusted World Product: A2**

| | $ trillion at 1990 values | | | Proportion of unadjusted | | Projection |
|---|---|---|---|---|---|---|
| | Unadjusted | "Most likely" | "Worst case" | "Most likely" | "Worst case" | $ trillion (1990) |
| 1990 | 20.1 | 20.1 | 20.1 | 100% | 100% | 20.1 |
| 2010 | 31.9 | 31.9 | 31.9 | 100% | 100% | 31.9 |
| 2035 | 61.8 | 61.8 | 60.8 | 100% | 98% | 61.3 |
| 2050 | 81.6 | 81.2 | 73.8 | 100% | 90% | 77.5 |
| 2075 | 136.7 | 122.3 | 70.9 | 89% | 52% | 96.6 |
| 2100 | 242.8 | 168.4 | 40.8 | 69% | 17% | 104.6 |

Source: See Appendix 4. The low 2010 estimate is shared by three of five A2 versions in the source tables, implying a very low rate of assumed growth in the first decade of the century.

An unmitigated A2 scenario would spell further disaster if we were to look beyond 2100.

The unadjusted growth for some unexplained reason shows an acceleration in economic growth between 2050 and 2075 (+68%) and 2075-2100 (+78%). Figure 5 in Appendix 4 shows the scenario to grow at a more irregular pattern from decade to decade than the other scenarios. This looks dubious but the most recent update still showed the irregularities. In any case, the actual world economic product would be considerably less than the unadjusted projection if the assumptions for Table 7.5 are correct.

### 7.4.6 THE UNITED STATES IN AN A2 CONTEXT

The dominant scenario according to Murphy (2007) in a regionalized economic world would be the impact of city-state economies which might deliver the upper end of a worldwide competitive situation that would see city-state powers elsewhere starting to compete for domination, perhaps either in cooperation or in competition with huge corporations. The net result (even within the US) would almost certainly be escalating conflict, aggravated as the world runs into growth constraints. The United States would most likely lose power and would be less likely, and able, to exercise its ability to resolve conflicts.

### 7.4.7 ZOOMING IN ON THE FLORIDA KEYS

Some of what is written under A1 (Section 7.2.7) applies here as well. But the situation is worse under A2, which appears to be one to be most strenuously avoided. That goes for the world, for the United States, and for the Keys. One factor would be real estate values, which would be lower than in A1. Any environmentally friendly legislation would be gone, and the Keys probably abandoned as a lost cause (the projected 13,000 inhabitants in 2100 may be either very rich or quite poor). It is unclear where a doubled population would find room in

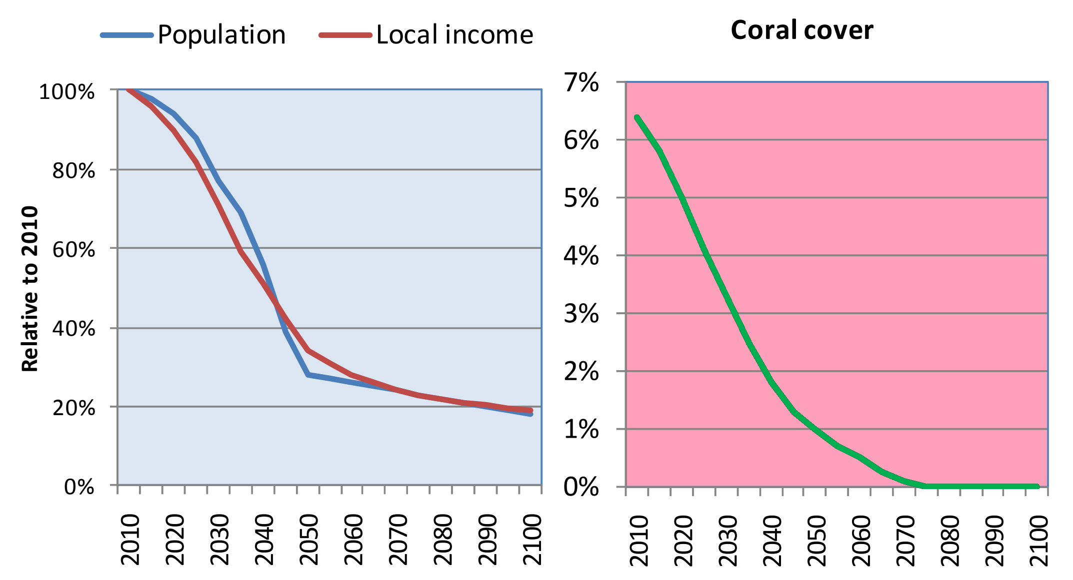
Florida, as estimated by Zwick and Carr (2006), as sea levels keep rising not just in the Keys but flooding Miami and surrounding urban areas as well, as well as other parts of the State.

**Table 7.8: Global and local projections for Scenario A2**

| Scenario A2 | 2010 | 2035 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Global temperature increase ($^{o}$C) | 0.8 | 2.2 | 3.2 | 3.8 | 4.4 |
| Global sea-level rise (cm) | - | 16 | 44 | 70 | 105 |
| Global ocean acidification (pH) | 8.1 | 8.0 | 7.9 | 7.8 | 7.7 |
| Annual world GDP change | 3.0% | 2.6% | 1.6% | 0.9% | 0.3% |
| Keys population | 72,000 | 49,700 | 20,200 | 16,600 | 13,000 |
| Population relative to 2010 | 100% | 69% | 28% | 23% | 18% |
| Keys coral cover | 6.4% | 2.5% | 1.0% | 0.0% | 0.0% |
| Coral cover relative to 2010 | 100% | 39% | 16% | 0% | 0% |
| Keys area remaining | 100% | 69% | 28% | 23% | 18% |
| Value of Keys area remaining | 100% | 79% | 53% | 45% | 37% |
| Keys income relative to 2010 | 100% | 59% | 34% | 23% | 19% |

The projected reduction of the Keys population to 13,000, with 82% inundation, and total income reduced to 19% of the level in 2010, is shown in Figure 7.8. Any remaining coral cover will disappear by 2075. All four variables represent a case worse than the A1 scenario.

**Figure 7.9: Scenario A2, Florida Keys**




## 7.5 B2: Regional environmental focus

### 7.5.1 The IPCC storyline

The B2 world is one of increased concern for environmental and social sustainability compared to the A2 storyline. Increasingly, government policies and business strategies at the national and local levels are influenced by environmentally aware citizens, with a trend toward local self-reliance and stronger communities. International institutions decline in importance, with a shift toward local and regional decision-making structures and institutions. Human welfare, equality, and environmental protection all have high priority, and they are addressed through community-based social solutions in addition to technical solutions, although implementation rates vary across regions.

Like the other scenario families, the B2 scenario family includes futures that can be seen as positive or negative. While the B2 storyline is basically neutral, a scenario from 1990 clearly paints a positive world with emphasis on decentralized governments and strong interpersonal relationships. In a 1995 scenario, values are only shared within small competing groups, which results in a decentralized world of tribes, clans, families, networks, and gangs. The IIASA-WEC "Middle Course" scenario from 1998, with slow removal of trade barriers, may also be grouped in this family. On the positive side, this storyline appears to be consistent with current institutional frameworks in the world and with the current technology dynamics. On the negative side is the relatively slow rate of development in general, but particularly in the currently developing parts of the world.

Education and welfare programs are pursued widely, which reduces mortality and, to a lesser extent, fertility. The population reaches about 10 billion people by 2100, consistent with both the UN and IIASA median projections [produced in 1996]. Income per capita grows at an intermediate rate to reach about US$12,000 by 2050. By 2100 the global economy might expand to reach some US$250 trillion. International income differences decrease, although not as rapidly as in storylines of higher global convergence. Local inequity is reduced considerably through the development of stronger community-support networks.

Generally, high educational levels promote both development and environmental protection. Indeed, environmental protection is one of the few truly international common priorities that remain in B2. However, strategies to address global environmental challenges are not of a central priority and are thus less successful compared to local and regional environmental response strategies. The governments have difficulty designing and implementing agreements that combine global environmental protection, even when this could be associated with mutual economic benefits.

The B2 storyline presents a particularly favorable climate for community initiative and social innovation, especially in view of the high educational levels. Technological frontiers are pushed less than they are in A1 and B1, and innovations are also regionally more heterogeneous. Globally, investment in energy R&D continues its current declining trend, and mechanisms for international diffusion of technology and know-how remain weaker than in scenarios A1 and B1 (but higher than in A2). Some regions with rapid economic development and limited natural resources place particular emphasis on technology development and bilateral cooperation. Technical change is therefore uneven. The energy intensity of GDP declines at about 1% per year, in line with the average historical experience since 1800.

Land-use management becomes better integrated at the local level in the B2 world. Urban and transport infrastructure is a particular focus of community innovation, and contributes to a low level of car dependence and less urban sprawl. An emphasis on food self-reliance contributes to a shift in dietary patterns toward local products, with relatively low meat consumption in countries with high population densities.

Energy systems differ from region to region, depending on the availability of natural resources. The need to use energy and other resources more efficiently spurs the development of less carbon-intensive technology in some regions. Environment policy cooperation at the regional level leads to success in the management of some trans-boundary environmental problems, such as acidification caused by sulfur dioxide ($SO_2$), especially to sustain regional self-reliance in agricultural production. Regional cooperation also results in lower emissions of nitrogen oxides ($NO_x$) and volatile organic compounds (VOCs), which reduce the incidence of elevated tropospheric ozone levels. Although globally the energy system remains predominantly hydrocarbon-based to 2100, a gradual transition occurs away from the current share of fossil resources in world energy supply, with a corresponding reduction in carbon intensity.

### 7.5.2 WOULD THIS SCENARIO STORY HAVE BEEN WRITTEN DIFFERENTLY IN 2010?

The defining feature of B2 is environmental awareness, encouraged in strong, well-educated and cohesive communities putting high priority on equality, health, and environmental protection. As distinct from one of its precursor scenarios, B2 does not mean societies dissolving into networks of tribes, clans, families, networks, and gangs, though apart from antisocial gangs these may help holding these societies together.

The regional structure, however, is big enough to allow for policies on equality, health and the environment to be successful, and there is sufficient communication across the globe to allow regions to cooperate on environmental protection, even though solutions differ at local and regional level. Regional size is not defined but might cover interlocking regional networks of everything from “the Indian subcontinent” through the State of Uttar Pradesh to one of its 70 districts from the capital Lucknow through village districts. The glue binding them together here remains the defining feature of environmental awareness, coupled with strong community values.

The role of technology in a B2 scenario written today would probably be viewed more positively than in the original, where it was seen as limiting economic growth with falling R&D expenditure and constraints on the international diffusion of technology and knowhow. It is also plausible in this well-educated world that the increasing threat from global climate change which has become apparent since 2000 has resulted in higher priority to strategies to address global environmental challenges – given that environmental protection was already one of the few truly international common priorities in the original B2 scenario.

Diffusion rates have increased greatly since B2 was written (Burns et al. 2008, Appendix 6), and there are signs that real innovation (as distinct from diffusion of existing technologies) is spreading beyond a few rich countries, to China, India, Brazil and elsewhere.

In contrast to the regionalized economic development scenario, A2, technological trends may be at play which could be successful at regional B2 level. B2 might benefit more from the fact that cell phones are rapidly permeating some of the poorest countries in Sub-Saharan Africa, to be followed by cheap Internet-connected computers (Standage 2009). The spread of Grameen Bank in Bangladesh and the internationalization of the concept through the Grameen Foundation is also based on strong community values. Furthermore, renewable energy technologies such as solar photovoltaics are proving beneficial and affordable at village level, and existing technologies aimed at improving biologically diverse agricultural methods and simultaneously helping trees and plants regain their role as $CO_2$ sinks are also highly applicable at local level. (See Appendix 6 for detail.)

This emphasis on small-scale technologies, which fits in with the strongly community-based approach in the B2 scenario, does not preclude large-scale projects. Some of the largest cities in the world are in Africa, and further urban growth will necessitate large-scale energy plants. A B2 regime would be sympathetic to compact urban design and other energy-saving developments, but large-scale solar and other renewable-energy plants will still be required.

The power and inflexibility of big government and big business have probably declined in a regionalized (de-globalized) world, and the storyline itself is explicit that concerned citizens have a bigger say. Finally, a continuous global population increase to over 10 billion by 2100 now looks excessive, given the reduction in total fertility rates across the world and given the assumed high educational level in the B2 world. Reaching 9 billion by 2050 may be almost inevitable, but some reduction may be realistic in the second half of the century.

Even before considering the evidence in the next section, we may find a more positive storyline to tell in the B2 quadrant of the tree diagram. Based on the greater urgency in dealing with climate change this includes the final statement in the storyline that energy supplies remain predominantly hydrocarbon-based until 2100 (increasingly favoring gas over oil). A rewritten B2 storyline might respond plausibly to the increased urgency to phase out fossil fuels at a faster rate (while still favoring gas over oil during the transition process), and the recent and current growth in renewable technologies that is becoming evident.

### 7.5.3 CURRENT PHYSICAL, ECONOMIC AND TECHNOLOGICAL INFLUENCES

The line taken in Appendix 3, tracing the escalating science-based demands for average global warming to remain below $2^{O}C$ above pre-industrial levels (and retaining atmospheric $CO_2$ levels at or below 350 ppm), would not put the original B2 scenario in as good a position as the global environmental scenario B1. But an updated B2 story may be closer.

As in B1 but with a more diverse pattern, economic policy will be sensitive to the economics of climate change, and will recognize and manage the "animal spirits" in the financial and commercial sectors (Appendix 4). In a world where community values play a bigger role, economics is also likely to adopt a more holistic approach, influenced by other social sciences, biology and other components inspired by complexity theory (Appendix 5).

While there will still be a need for large renewable technology solutions, these are unlikely to be dominated by environmentally hazardous schemes like covering large parts of the Sahara desert with photovoltaic elements or concentrated solar power plants to fill European power needs. Genetically modified crops will be needed for food security reasons, and will be encouraged by large biotech companies seeing an social and even financial advantage in giving preferential treatment to farmers in poor nations (*The Economist* 2009).

Generally, however, agricultural technologies aimed at combining biodiversity with productivity would appeal most in this strongly community-based scenario. Appendix 6 names a number of such technologies, for example Vendana Shiva's "nine crops" program which aims specifically at improving biodiversity through agricultural practices in India (Shiva

2005). It fits in well with the diversity in this regionalized scenario that there is a wide range of possible solutions to fit different agricultural conditions.

The B2 story, as written, shares the position of lowest economic growth with the regionalized economic growth scenario A2. In the best case (Appendix 4, Figure 3), B2 grows continuously to $200+ trillion, and the "most likely" case by almost as much. However, the worst case has B2 at a maximum of $150 trillion in 2080, following by decline, presumably due to increasing population pressures towards the end of the century.

This contrasts with the B1 scenario, which shows continuous economic growth to about $270 trillion, but a rewritten B2 scenario may get closer, perhaps halfway between B1 and the original B2. Moreover, there are features in B2, notably the strong community spirit and commitment to local and regional causes, that could well be copied into an enhanced B1 scenario.

### 7.5.4 Linking the present to the storyline

An interruption of the globalization trend during the 2010s may have similar economic causes to those postulated for the regional growth-driven A2, but the reaction will be different. Though the world economy meets protracted difficulties in recovering from recession, the reaction of its citizenry is different.

Some performances by Mother Nature during the early 2010s in the heat wave, drought, monsoon, and hurricane departments, help convince a majority across the planet that urgent action is needed. The Deepwater Horizon oil spill in 2010 also made its mark, attracting attention to the plight of the largest coastal wetlands in the nation, in Louisiana, and at a basic emotional level through images of distressed pelicans drenched in oil. The B2 world, as described, also has closer cooperation between regions than A2. In particular, the climate change talks continue in a constructive vein, despite continued lackluster economic growth. At COP-17 in December 2011 formal agreement is reached to move towards drastic reduction in greenhouse gas emissions consistent with an eventual level of <350 ppm atmospheric $CO_2$, which became the science-based norm in 2009.

B2 is another scenario that should be significantly rewritten compared with its treatment in the decade-old Third Assessment Report, but in contrast to A2 it is now viewed more positively. Technological development and diffusion in particular are likely to be faster, and will favor the development of many "small" technologies benefiting local communities, as well as the replacement of fossil energy with renewables long before the end of the century, as distinct from the original B2 scenario. These technologies will coexist with larger projects needed for the generation of power and presumably for the development of green biotech schemes. The resulting mixed pattern of mainly renewable small- and large-scale technologies should be clearly visible in this scenario by the mid 2020s.

### 7.5.5 Global path to 2100 and beyond

The top panel of Table 7.9 shows the original B2 scenario in its unadjusted form, and after being subjected to the constraints caused by a rise of global temperatures according to the model in Appendix 4. The growth in the unadjusted model is slightly lower than for A2, but irregularities in the latter must be treated with some caution, as noted under A2.

| | $ trillion at 1990 values | | | Proportion of unadjusted | | Projection |
|---|---|---|---|---|---|---|
| | Unadjusted | "Most likely" | "Worst case" | "Most likely" | "Worst case" | $ trillion (1990) |
| | As per original scenario in 2000 | | | | | |
| 1990 | 20.9 | 20.9 | 20.9 | 100% | 100% | 20.9 |
| 2010 | 38.6 | 38.6 | 38.6 | 100% | 100% | 38.6 |
| 2035 | 75.8 | 75.8 | 75.8 | 100% | 100% | 75.8 |
| 2050 | 109.5 | 109.5 | 107.5 | 100% | 98% | 108.5 |
| 2075 | 173.9 | 169.5 | 146.7 | 97% | 84% | 158.1 |
| 2100 | 234.9 | 212.5 | 132.4 | 90% | 56% | 172.5 |
| | Adjusted to new estimate in 2009 (average of original estimate and B1) | | | | | |
| 1990 | 20.9 | 20.9 | 20.9 | 100% | 100% | 20.9 |
| 2010 | 38.6 | 38.6 | 38.6 | 100% | 100% | 38.6 |
| 2035 | 81.4 | 81.4 | 81.4 | 100% | 100% | 81.4 |
| 2050 | 122.6 | 122.6 | 121.6 | 100% | 99% | 122.1 |
| 2075 | 201.5 | 199.3 | 180.7 | 99% | 90% | 190.0 |
| 2100 | 281.7 | 265.9 | 201.4 | 94% | 72% | 233.7 |

**Table 7.9: Unadjusted and adjusted World Product: B2**

Source: See Appendix 4

Even before being adjusted upwards, the “most likely” case taking global warming into account compares well with the unadjusted case: it comes within 10% even in 2100. In the worst case, the global economy starts to decline in the last quarter century, to reach only 56% of the unadjusted scenario path in 2100.

B2 should be increased in the light of new knowledge since the scenarios were built. The lower panel of Table 7.9 assumes that the difference between B1 and B2 is cut in half. According to Appendix 4 (Table 1), the best, most likely and worst cases for B2 are +1.7$^{O}$C, +2.4$^{O}$C, and +3.8$^{O}$C, compared with +1.1$^{O}$C, +1.8$^{O}$C, and +2.9$^{O}$C for B1. The revised B2 therefore uses +1.4$^{O}$C as best, +2.1$^{O}$C as most likely, and +3.3$^{O}$C as worst case. The unadjusted path has also been increased by half of the difference between B1 and the original B2. As a result, B2 now fares even better in the most likely case, losing only 6% compared with the new unadjusted path. The worst case loses 28% by 2100, mainly in the last quarter of the century. While even the worst case shows continued growth, it is getting close to zero by 2100.

Greenhouse gas levels will be too high under the adjusted B2 scenario, though not much more so than B1 judging from Table 1 (Appendix 4). The estimated level of atmospheric $CO_2$ in 2100 in the unadjusted B2 scenario is 616 ppm, compared with 545 ppm for B1. This suggests about 570 ppm for the revised B2.

These figures are illustrative only. Nevertheless, the update is probably more realistic than the original scenario, given the new developments.

If the world is to reduce $CO_2$ levels quickly towards 350 ppm (and other greenhouse gases in proportion), B1 remains the most promising scenario for the 21$^{st}$ century and beyond. However, B2 has some attractive features, such as the engagement of a large number of actors at different regional levels, which might be helpful in reinforcing the B1 scenario.

Encouragement of a strong local community spirit would be very important for the effort to promote all relevant technologies to achieve the 350 ppm $CO_2$ target. Such a community spirit exists in many places already, including the Florida Keys. It won't happen, however, if the current upward trend in the number of climate deniers continues. The need to get a large majority of the world's population to understand the climate change threat and become actively engaged is urgent and critical for success – and perhaps more difficult to achieve than before based on the experience during 2009.

### 7.5.6 THE UNITED STATES IN A B2 CONTEXT

The best hope for the United States would be that the community spirit outlined in the previous sections would be reflected here. This community spirit would not eliminate the risks of factors such as sea-level rise, but it would generate a momentum towards consciousness of the risks and taking effective action. The spirit would permeate everything from national to local effort, spearheaded by those regions most at risk, including the Florida Keys. The advocacy at that level, evidenced by local organizations such as the Sanctuary Friends Foundation of the Florida Keys (SFFFK) and Green Living and Energy Education (GLEE), will prove to be of vital importance in the promotion.

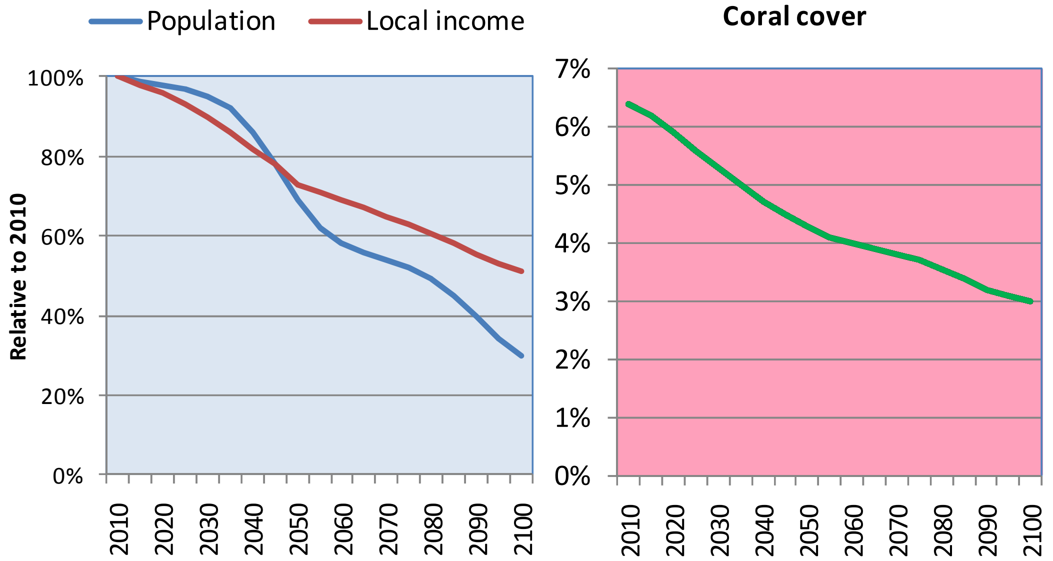
### 7.5.7 ZOOMING IN ON THE FLORIDA KEYS

**Table 7.10: Global and local projections for Scenario B2**

| Scenario B2 | 2010 | 2035 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Global temperature increase ($^oC$) | 0.8 | 1.6 | 2.2 | 2.6 | 3.0 |
| Global sea-level rise (cm) | - | 7 | 16 | 25 | 37 |
| Global ocean acidification (pH) | 8.10 | 8.05 | 8.00 | 7.95 | 7.90 |
| Annual world GDP change | 3.0% | 3.0% | 2.7% | 1.8% | 0.8% |
| Keys population | 72,000 | 66,200 | 49,700 | 36,700 | 21,600 |
| Population relative to 2010 | 100% | 92% | 69% | 51% | 30% |
| Keys coral cover | 6.4% | 5.0% | 4.3% | 3.7% | 3.0% |
| Coral cover relative to 2010 | 100% | 78% | 67% | 58% | 47% |
| Keys area remaining | 100% | 92% | 69% | 51% | 30% |
| Value of Keys area remaining | 100% | 94% | 79% | 68% | 56% |
| Keys income relative to 2010 | 100% | 86% | 73% | 63% | 51% |

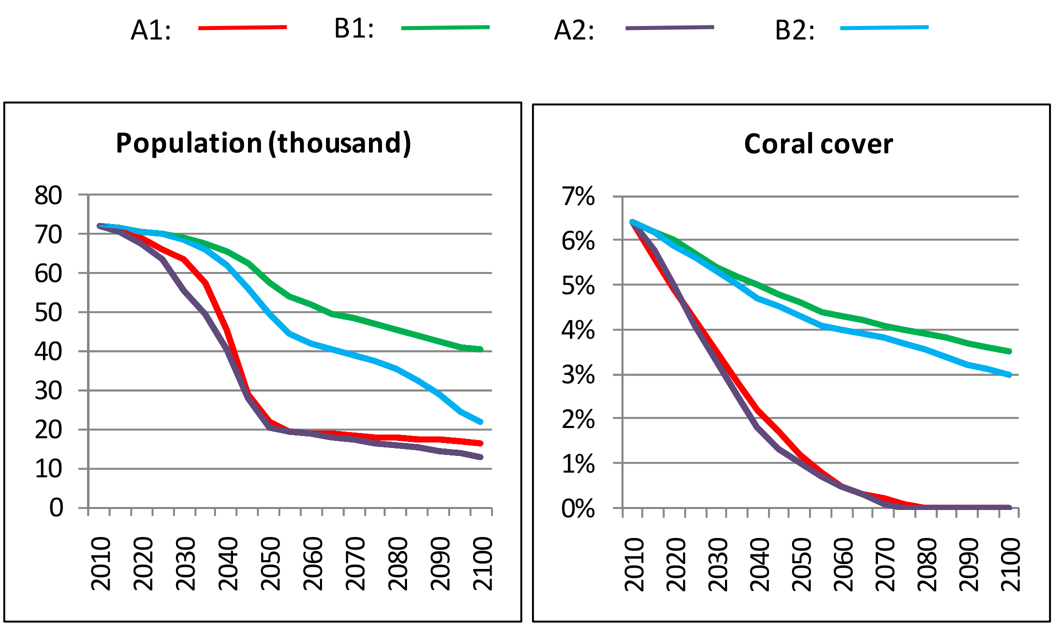
While not as positive as B1, the limited information available suggests that the community-based support and environmental orientation makes this the second-most positive scenario. It contrasts favorably with the bleak local prospects of the other regionalized scenario, A2, to demonstrate that social cohesion and a strong sense of community and respect for the environment will go a long way, given that B2 would be judged more favorably today than when it was created. It assumes that the work on coral reef resilience will continue under an active and strong sanctuary management supported by other organizations and groups, and that the natural land-based and historic environment will be preserved to the maximum extent in the face of the rising sea level, all strongly and actively backed by the community. Furthermore, marine-based tourism will continue to make a significant contribution, based on a residual coral cover assumed to decline from the current 6.4% to 3% in 2100.

**Figure 7.10: Scenario B2, Florida Keys**




The summary indicators for the Keys are shown in Figure 7.10. Based on the sea-level rise projected by Bergh (2009) on the basis of the actual topography and elevations of the Keys, the population projection deteriorates between 2075 and 2100 (as it did more seriously in the B1 and B2 scenarios between 2035 and 2050). This may serve as a reminder that there is no “safe” projection when dealing with climate change and sea-level rise.

**Figure 7.11: Comparative scenarios, Florida Keys**



## 7.6 COMPARISON

Figure 7.8 shows some main trajectories for all four scenarios on one chart. The indicators are population (number of persons rather than the decline compared to 2010 shown on the previous graphs) and coral cover.

The scenarios form two groups: A1 and A2 are the most unfavorable, B1 and B2 the most favorable (with the proviso that B2 shows an unfavorable trend after 2075 related to the elevation pattern of the Keys). The regional scenario version is less favorable than the globalized version for both sets. The margin, however, is still generally wide between the regionalized environmental scenario, B2, and the “balanced” renewable/fossil version of the global economic scenario, A1B.

# 8 POLICY RECOMMENDATIONS

## 8.1 GUIDANCE FROM OTHER RESEARCH

The policy recommendations represent the ultimate outcome of this project, following the approach in the report on the Great Barrier Reef which provided the model. The provision of policy recommendations was a requirement (Hoegh-Guldberg 2005, p 7 and elsewhere).

Other reports are quoted in support, bringing different perspectives to the final recommendations. The first is a study of the Coral Triangle in Southeast Asia (Hoegh-Guldberg et al. 2009). The lead author was Ove Hoegh-Guldberg with co-authors including this writer (economics and scenarios) and Lara Hansen, chief scientist and executive director of EcoAdapt, who drafted the policy recommendations. With her colleague Alessandra Score, formerly WWF's Florida program marine conservation specialist, she adapted a set of annotated Coral Triangle recommendations to suit the Florida Keys. Their insights are essential, generally agreed upon, and gratefully acknowledged. Adapted to the Keys, they qualify as a prime set of final recommendations.

The other selected reports are the second US Global Change Research Report (Karl et al. 2009) and the TNC report on sea-level rise in the Keys (Bergh 2009). Concluding comments and an attempted synthesis follow at the end of Chapter 8.

### 8.1.1 ADAPTABILITY OF CORAL TRIANGLE ISSUES TO THE FLORIDA KEYS

The Coral Triangle covers some of the most prolific and biologically diverse coral reefs in the world, located off Eastern Indonesia, Sabah, the Philippines, Timor Leste, Papua New Guinea, and the Solomon Islands (Hoegh-Guldberg et al. 2009). The recommendations of that report are truly policy-related, from global to local level.

The list below shows each Coral Triangle recommendation adapted to incorporate Lara Hansen's and Alex Score's observations relating to the Florida Keys, with some added observations from the author's own experience. They form a very important step toward a final set of recommendations because of their local insight. Each item in the Coral Triangle list was edited but remains easily recognizable compared to the original one, shown at the end of the executive summary of the Coral Triangle report. The agreement is striking between the issues evoked about the largest and most biologically diverse coral reef system in the developing world, and the Florida Keys, located in a vastly different physical and socioeconomic setting.

It is also implicit in the amended recommendations that the Keys form a "higher-order" ecosystem (discussed in Chapter 3.3) – all component ecosystems and socioeconomic structures are interrelated and subject to threat if the total Keys system is threatened.

The amended and annotated list of recommendations for the Keys follows:

1. *Create a binding international agreement to reduce the rate and extent of climate change.*

   Emissions should peak no later than 2020 (preferably by 2015), and global warming should be limited to well below 2$^{O}$C above pre-industrial temperatures by 2100, to keep atmospheric $CO_2$ below 350 ppm. This will require steep global cuts in emissions that are at least 80% below 1990 levels by 2050. Inherent to this recommendation is the creation of an aggregate group reduction target for developed countries of 40% below 1990 levels by 2020, and a reduction from emission levels for developing countries of at least 30% by 2020.

2. *Take immediate action to establish national, state and local county targets and plans to meet these commitments such that the international agreement can be achieved.*

   This report shows that the Florida Keys have a great deal at stake if climate change continues unchecked, more than practically any other part of the nation. Monroe County and other authorities must become part of the solution and must do this expeditiously. This can start with meeting targets at the local county level, while simultaneously acting as a major voice pushing for state and national reductions (directly and in cooperation with other local governments). Lag-times and non-linear responses in the climate system mean that for every day we wait to take action, the problem becomes dramatically more difficult and costly to address successfully. This will hit Floridians at home – personally, socially and economically.

3. *Pursue the establishment of integrated coastal and marine zone management across the region to reverse the decline of the health of coastal ecosystems*.

   This should include a partnership between the federal, state, and local governments across jurisdictional boundaries for the implementation of policies that ideally eliminate further coastal development, reduce pollution, expand marine protected areas, regulate fishing pressures and abolish destructive practices. The recommendation harmonizes with the existing integrated coastal management philosophy of the FKNMS which is based on cooperation with multiple local, state and national jurisdictions. It is important that these actions do not aim to restore or protect ecosystems for past conditions, rather they must prepare for conditions under a changing climate that allow for migration and adaptation.

4. *Support the establishment of a Florida Keys "climate change fund" to meet the adaptation needs of this sensitive and vulnerable critical ecosystem*.

   While some of the cost of adapting to climate change can be met by redirecting current resources that are being used in a manner that is vulnerable to climate change, the growing challenge of climate change will result in new and increasing costs. Funds will be required to meet these costs given that the hardship caused by the climate change in Florida will be felt disproportionately in the Florida Keys. National and state funds will be necessary to meet these challenges. Funds for ecosystems and for human communities will both be needed and the efficacy of each will rely on coordination between the two.

5. *Build adjustable financial mechanisms into national and state budgeting to help cover the increasing costs of adaptation to climate change in the State of Florida*.

   Climate change will require not only new funds, but also a reassessment of current spending so that funds are spent in ways that are "climate-smart", in other words on efforts that are resilient to climate change. Every effort should be made to avoid spending funds and taking actions that exacerbate the problem of climate change, such as building new coal-fired plants, oil drilling off the coasts of Florida and continuing to develop and insure infrastructure along Florida’s vulnerable coast.

(This was written before President Obama’s announcement, on March 31, 2010, to allow oil and gas exploration to “responsibly expand'' drilling in new areas like the eastern Gulf of Mexico, 125 miles off Florida's coast, as well as in the Atlantic as far south as Central Florida. It was consequently also written before disaster hit BP’s Deepwater Horizon operation in May. The above recommendation remains unaltered.)

6. *Integrate resource protection into the Florida Keys development master plans to provide robust holistic protection in the face of climate change*.

   Adaptation plans cannot be developed on a sector-by-sector basis. Doing so risks creating problems such as adaptation being effective against one issue but maladaptive against another. It will be important to plan holistically and create governance structures that can support, implement and monitor these efforts.

7. *Build the socio-ecological resilience of coastal ecosystems and develop stakeholder and community engagement processes for communities to improve their ability to survive climate change impacts*.

   Involving coastal people and communities in planning provides greater stability and efficacy for solutions to social and ecological challenges within the Florida Keys. Fundamentally, it will be local knowledge that generates innovative adaptation strategies which may prove most successful. Reducing the influence of local stress factors on coastal ecosystems makes them able to better survive climate change impacts. Protecting the diversity of components (communities, populations, and species) under the guidance and actions of local people strengthens the resolve of these systems in the face of climate change. As described at the end of Chapter 4, the Florida Keys are fortunate to already have a strong community understanding of the issues.

8. *Build capacity to engage in planning for climate change. Climate change planning, both mitigation and adaptation, will require that we educate current and future practitioners, as well as the concerned constituencies*.

   Mechanisms must be created to develop current resource managers and planners so that they can immediately implement these new approaches. As the problem of climate change is not one that we will be solving in this generation, planning and responses to climate change will be iterative as the target continues to move over the coming centuries. Therefore, it will also be necessary to develop training for future capacity through education in academic settings. Informed stakeholder and community engagement is at the core of successful adaptation, so in addition to professionals and students, civil society must be given access to the information they need to understand and respond to climate change. In fact, developing a trained and informed community in the Florida Keys could develop a stronger sense of community and camaraderie in the Keys which will be needed to endure this major challenge.

9. *Integrate climate change adaptation into all conservation and development efforts at the local, national and regional levels and revise current plans for their robustness in the face of climate change*.

"Business-as-usual" conservation and development will not achieve success. The new mode of action requires integration between conservation and development, and the realization that many past approaches are no longer effective due to the impacts of climate change. The Florida Keys are inherently vulnerable to climate change. Their best chance, assuming that global action is taken to reduce greenhouse gas emissions and slow the rate and extent of climate change, is to increase the resilience of the system as a whole. No decision should be made in the Florida Keys that is not "climate smart."

10. *Focus adaptation throughout Florida on playing a role in economic stimulus, especially in job creation and financial mobilization. Incentives can also be in new "climate smart" development*. (Note: The recommendation could be extended to cover all States in the Southeast, or nationally.)

    Private-public sector incentive schemes, regional/state arrangements and investment partnerships (e.g. national insurance reform and special-access loan schemes) need to better incorporate risk management and adaptation strategies to reduce investment risk and maintain positive financial conditions.

In summary, the adapted Coral Triangle recommendations fall roughly into three groups:

- *Internationally*, it is urgent to achieve binding international agreement on emissions cuts, supported on national and regional targets in all countries (items 1-2)
- *Locally* (supported at state and national level), integrated coastal and marine management is essential, including funding for the Keys as an area at particular risk, holistic planning and building both socioeconomic and ecological resilience. Educate to develop a trained and informed community to better mitigate and adapt to climate change (items 3-8)
- *At all levels from local to national*, adapt existing conservation and development efforts for climate change robustness, and plan for adaptation efforts to play a role in economic stimulus and achieve "climate-smart" development (items 9-10).

### 8.1.2 THE GLOBAL CHANGE RESEARCH PROGRAM REPORT

Being the first report since 2000 to provide an extensive evaluation of regional climate change impacts on the United States, its recommendations are pertinent to our own policy advice. They present another inspiring, useful and relevant list in their own right. Although there is some overlap, the perspective differs from the adapted Coral Triangle recommendations, by advocating a more influential and stronger climate science as a prerequisite to tackle policy and advocacy issues with maximum conviction and certainty.

Both sets of viewpoints are legitimate and necessary. Scientific knowledge is essential but incomplete; scientists are painfully aware of the uncertainty that still attach to climate models, especially as it plays into the hand of climate change deniers among the public, politicians, and business, whether their views are due to genuine skepticism, ignorance, or vested interests. This is an growing cause for concern as climate change becomes more ominous but still appears to many non-scientists to be decades away.

The recommendations are reproduced below with essential annotations from the accompanying text (for the full version refer Karl et al. 2008, pp 153-156):

1. *Expand our understanding of climate change impacts* on ecosystems, economic systems, human health, and the built environment. Ecosystem changes include changes in the chemistry of the atmosphere and precipitation, vegetation patterns, growing season length, plant productivity, animal species distributions, and the frequency and severity of pest outbreaks and fires. In the marine environment, changes include the health of corals and other organisms suffering from temperature stress and ocean acidification. In addition to observations, large-scale whole-ecosystem experiments are essential for improving projections of impacts, especially for ecosystems risking massive change due to the crossing of thresholds or tipping points.
2. *Refine ability to project climate change, including extreme events, at local scale*. Climate change is a global issue but has a great deal of regional variability. There is an indisputable need to improve understanding of climate system effects at regional scales, which are often the scales of decision making in society. "Continued development of improved, higher resolution global climate models, increased computational capacity, extensive climate model experiments, and improved downscaling methods will increase the value of geographically specific climate projections for decision makers in government, business, and the general population." (p 154)
3. *Expand capacity to provide decision makers and the public with relevant information on climate change and its impacts*. There are significant data gaps, including damage cost. Services that provide reliable, well-documented, and easily used climate information should be made available to support users.
4. *Improve understanding of thresholds likely to lead to abrupt changes in climate or ecosystems.* There are key risks to society for which understanding is still quite limited such as thresholds leading to rapid changes in ice sheet dynamics, causing sea-level rise. The increasing concern about ocean acidification has created a need to establish acidity thresholds beyond which corals and other organisms, including those at the base of marine food chains, can no longer form shells for their body structure to survive.
5. *Improve understanding of the most effective ways to reduce the rate and magnitude of climate change, as well as unintended consequences of such activities.* Impacts of climate change are projected to be by far the largest and most rapid in scenarios in which greenhouse gas concentrations continue to grow rapidly. Additional research will help identify the desired mix of mitigation options necessary to control the rate and magnitude of climate change. Unintended consequences of mitigation options (such as competing use of land, water and other resources) need to be explored to help decision makers make better choices on possible trade-offs inherent in various mitigation strategies.
6. *Enhance understanding of how society can adapt to climate change.* Not enough is known on the potential cost of adaptation measures. "It is important to improve understanding of how to enhance society's capacity to adapt to a changing climate in the context of other environmental stresses. Interdisciplinary research on adaptation that takes into account the interconnectedness of the Earth system and the complex nature of the social, political, and economic environment in which adaptation decisions must be made would be central to this effort." (p 156)

In summary, these six recommendations concern how to remedy lack of scientific knowledge to allow the evidence to be presented as convincingly and unequivocally as possible. Scientifically, we don't know enough about the impact of climate change on ecosystems and human systems, how to project local climate change, the thresholds to abrupt climate change, and the systems controlling climate change and how to avoid unintended effects from mitigation options (items 1,2 4 and 5).

We are also short on information on damage and other costs, and the cost of adaptation in the context of other environmental stresses (items 3 and 6).

The second group is primarily about the cost of adapting to climate change, which would vary with local factors and therefore most amenable to a microeconomic approach.

### 8.1.3 STRATEGIES RELATED TO SEA-LEVEL RISE IN THE KEYS

Sea-level rise (SLR) is potentially the most serious effect of climate change in the Keys. Proactive response strategies will take two general forms: mitigation and adaptation. It is important to consider specific planning approaches proposed to mitigate against further sea-level rise, and adapt to it. This section is based on the concluding section of Chris Bergh's 2009 paper, which also showed, at least by implication, how everything in the Keys hangs together in a "super" or "higher-order" ecosystem.

*Mitigation of the root causes of climate change and SLR must take place at every scale from the global to the local in order for the Florida Keys to experience any appreciable reduction in the local SLR*

This includes International, national, and state agreements, municipal laws, and regulations and codes to address climate change mitigation. Monroe County's Green Initiatives Task Force and local government "green teams" play an increasing role in developing and tracking mitigation actions. The influence of community organizations is described in Section 4.4.

*Mitigation activities notwithstanding, the Florida Keys will experience SLR-driven changes that will incrementally diminish the viability of terrestrial plants, animals and natural communities while creating new marine habitat of uncertain quality*

Miami-Dade County's Climate Change Advisory Task Force recommends support for the Comprehensive Everglades Restoration Plan as a restored Everglades ecosystem will be better able to resist SLR-driven change and protect South Florida's freshwater supply. Examples of SLR adaptation planning by government entities are relatively few in the Florida Keys, but that is changing. The Fish and Wildlife Service is incorporating SLR estimates in its management planning, and the City of Key West is beginning to factor SLR into its engineering and construction decisions.

Ross et al. (2009) lay out a compelling argument for helping natural areas and ecosystems adapt to both the incremental long-term effects of SLR and acute disturbances such as storm surges and forest fires. Their approach calls for identification of "core areas" with the best chances of persistence during SLR, intensive management of core areas to minimize loss of biodiversity, and relocation of vulnerable species to less vulnerable areas.

Identifying core areas will not be as simple as choosing the highest ground, although elevation is a critical component. Other important components include representation of all habitat types and species; replication of core areas so the impact of a single unmanageable event, such as a severe storm surge, is less likely to damage all habitat or species occurrences; connectivity through biological corridors or other means; and effective management of core areas.

*Managing for resilience and adaptation to SLR*

The concept of resilience is central to the strategies to preserve ecosystems in the Florida Keys. Section 4.3 focuses on the Florida Reef Resilience Program to minimize human-induced stresses on local coral reefs. But resilience applies more generally: "Entire ecosystems, core areas, species populations, individual organisms, and even human communities with their built environment and industries all possess a measure of resilience that can be enhanced or degraded." (Bergh 2009, p 29)

*"No regrets" strategies for managing Florida Keys natural areas for SLR*

Several management strategies, which have been practiced in the Keys for decades, increase the resilience of natural areas and native species to SLR. These strategies include:

- Fire management of pine rock-land forests, found only in the Lower Keys, southern Miami-Dade County, the Bahamas and Caicos islands. These fire-dependent forest communities sustain a remarkably rich diversity of flora and fauna. Of the eleven Lower Keys supporting pine rocklands, five (Upper Sugarloaf, Cudjoe, Big Pine, No Name, and Little Pine) have sufficient acreage for management in a prescribed fire context (Bergh and Wisby 1996). The pine in question is the south Florida slash pine (*Pinus ellioti* var. *densa*).
- Management of invasive exotic species that degrade natural areas by directly competing with native species that have life history requirements similar to those of the invader. *Casuarina* species known locally as Australian pine destabilize dunes and other coastal habitats that are the front line of natural defense against storm surges and coastal erosion which will be exacerbated by SLR. Salt-tolerant species including the Asian *Colubrina asiatica* and *Scaevola sericea* which invaded the US mainland from Hawaii take over from less salt-tolerant local species.
- Restoration of Florida Keys wetland habitats. In the course of developing the Florida Keys, people filled many freshwater, brackish and saltwater wetlands, drained others via ditching, and fragmented others in the course of constructing raised roadbeds. Freshwater wetlands are therefore among the rarest habitat types in the Keys and they are critically important to many wildlife species.

*Problems and promises of off-site conservation approaches*

Resilience-based planning and management for terrestrial systems and species will not eliminate the eventual need for implementation of "ex-situ" or off-site conservation strategies, but they will help stave off that need. Ex-situ strategies, while perhaps necessary to prevent extinction of species and subspecies endemic to the Florida Keys, are fraught with uncertainty and risk (and they won't save the Keys from inundation). Long-term monitoring of any species introduced into a new habitat, and their impacts on their new habitat and native species, must be part of the plan.

*Managing today for tomorrow's marine ecosystem*

The following statement would apply fully to a "business-as-usual" scenario although losses are also expected in more benign situations: "Intensive management of core areas, while appropriate and necessary, ultimately will not prevent the wholesale transformation of terrestrial habitat into new marine habitat under current SLR projections. The Florida Keys — including core areas which will hold out the longest, particularly if they are intensively managed — will become marine habitat and are likely to remain marine habitat for many millennia thereafter. In light of this, intensive management should not include activities that will result in compromised marine habitat quality in the future." (Bergh 2009, p 31)

*Conclusion*

"Sea-level rise is real now and all indications are that the rate of rise will accelerate in the coming decades. Unlike the acute impacts of a hurricane, which the Florida Keys have historically withstood or recovered from, the impacts wrought by SLR will be permanent. Mitigation of the root causes of climate change and sea-level rise may slow or reduce its impact, but significant change is inevitable. Natural areas, native species and human communities will have no choice but to adapt. Decisions made today will influence, sometimes profoundly, the ability of people and nature to adapt to SLR in the future." (p 32)

*Summary*

Research into sea-level rise is central to the understanding of the potential impact of climate change in the Keys. It adds an important dimension to the proposed policy recommendations in the two previous sections, which were based on the Coral Triangle study and the second report of the US Global Change Research Program, respectively.

In summary, climate change, including sea-level rise, is determined by global forces but mitigation must take place at every level down to local regulations and recommendations by "green teams". Change driven by sea-level rise will happen regardless of mitigation efforts, and management efforts must address resilience and adaptation, including "no regrets" strategies like fire management of Lower Keys pine rocklands, management of invasive species, and restoration of wetland habitats. Eventually, however, the Florida Keys will become at least partly a marine habitat, a transition that must not be compromised by current management practices.

## 8.2 POLICY RECOMMENDATIONS FOR THE FLORIDA KEYS

### 8.2.1 WHAT THE SELECTED REPORTS DIDN'T REVEAL

The three reports featured in the previous section provide different perspectives, all highly relevant. The recommendations derived from the Coral Triangle study provide essential general and specific policy directions adapted to the Keys situation. The US Global Change Research Program report is a reminder that there is work to be done to improve the scientific knowledge to reduce the uncertainties surrounding the projected impacts, and convey a more convincing public message. Finally, Chris Bergh's work serves as a stark reminder of the worst risk facing the Florida Keys, sea-level rise, but in a very positive sense it also highlights the importance managing and planning for resilience. We have secured great insights, relevant to the Keys, into:

- General and specific policy recommendations for local, statewide, and national adoption
- Recommendations aimed at reducing the uncertainty of climate science models by improving the research, as a condition for greater and more convincing advocacy
- Highlighting the worst climate change problem facing the Florida Keys, sea-level rise, while stressing the importance of encouraging resilience of natural and human systems.

None of the three reports deals with the influence of technological change, identified as a key driver of future scenarios by the IPCC and therefore a natural focus in this study. Figure 7.1 (Section 7.1.1) identifies the drivers of greenhouse gas emissions as population, economy, energy and technology, and land use. Energy and technology go hand in hand. Appendix 6 presents a comprehensive picture of technology in relation to climate change, dealing with its main dimensions of physical technologies (based on fossil-based sources, renewables, and nuclear power), energy efficiency measures, and "green" and "blue" carbon approaches to improve and add to carbon sinks.

Another dimension, for a long time quite unrecognized, is the influence of economic theory on government policy (Appendix 5). The prime recent example is how economics became dominated by the neoclassical school that (crudely expressed) taught that the market was right and should be allowed as much freedom as possible. There is a direct link between this school of thought and the circumstances leading to the current economic crisis. Furthermore, climate change economics emerged too late to become mainstream. Coming from other ways of thinking, the three reports we canvassed for policy advice contain no reference to the influence of economic theory on macroeconomic and financial policy.

Applying scenario planning, long advocated by the IPCC and a requirement in the current study, ensures that all relevant socio-cultural, technological, economic, environmental and political variables are taken into account in describing possible futures. Technological and economic change are explicitly included.

### 8.2.2 WHAT THE SCENARIOS DO TELL US

The scenarios outlined in Chapter 7 leave little doubt that a "business-as-usual" approach would be verging on the suicidal, and the global economically based scenario A1 is too close for comfort to "business-as-usual." The only way forward is for the world to mobilize itself as fast as possible to expand to renewable technology, major energy efficiency measures, and the spread of green land-based technological change involving all nations, rich and poor.

The survival of the Florida Keys, with minimal damage from sea-level change and a reasonable hope to maintain some coral cover, depends on the comprehensive global adoption of environmental policies and rapid reduction of greenhouse-gas emissions. The adapted recommendations from the Coral Triangle study in Section 8.1.1 stress the need to tackle these issues globally, through effective and binding international agreements to reduce emissions. Local action is important in the interest of generating resilience, but the global commitment to reduce emissions is a precondition for success.

### 8.2.3 KEY FACTORS

This last section contains a proposed synthesis, starting with a summary of the adjusted Coral Triangle recommendations:

- *Internationally*, it is urgent to achieve binding international agreement on emissions cuts, supported by national and regional targets in all countries.
- *Locally* (supported at state and national level), integrated coastal and marine management is essential, including funding for the Keys as an area at particular risk, holistic planning and building socio-ecological resilience. It should be underpinned by education and outreach to develop a prepared and informed community to better mitigate and adapt to climate change.
- *At all levels from local to national*, adapt existing conservation and development efforts for climate change robustness, and plan for adaptation efforts to play a role in economic stimulus and achieve "climate-smart" development.

The following list is presented as a possible synthesis further inspired by the specific findings of this research. It progresses from global to local perspectives:

1. There is overwhelming scientific consensus that climate change has become the most critically urgent issue of our time. There is an pressing need for effective international climate change mitigation now to limit the need to have to adapt in future.
2. Non-linear positive feedback responses in the climate system will become more frequent; intensified controlling action is urgently required. This is behind the targets to reduce greenhouse gas emissions by at least 80% by 2050, to stay below a $2^{O}C$ global temperature rise and 350 ppm $CO_2$. It is not just a matter for international negotiators; constant local, state and national action is required to reinforce and re-educate.
3. It is essential, therefore, to work toward an effective and binding international agreement on emissions control, with the onus on the developed world. Define substantial points for negotiation in time for the climate change conference in Mexico in December 2010 (COP-16) and achieve binding agreement for an effective successor to the Kyoto Protocol at the very latest at COP-17 in South Africa, in December 2011.
4. An environmentally friendly global scenario exemplified by the updated version of IPCC's "B1" is vital for long-term survival, backed by a prevailing spirit of strong community involvement. Continued encouragement of environmentally sensitive policies encompassing all nations is a primary objective, whatever it takes.
5. The political process in many leading countries has temporarily lost its sense of urgency and needs a wake-up call. The United States, as world leader, needs to ensure the passage of effective climate legislation through the Senate in 2010, but political reality suggests 2011. It must happen then.
6. It is high priority to promote and fund more research into new technologies including not only renewables but also energy efficiency and the protection of rural and coastal carbon sinks, plus the international diffusion of all renewable technologies, big and small, to the developing world. Diffusion is important to get the whole planet involved.
7. The Florida Keys are the most threatened area in the most threatened mainland State in the nation. They would not survive in a "business-as-usual" scenario. This gives the Keys as a mainstream American community a unique voice in the advocacy.

8. The existing strength of the integrated coastal management philosophy forms a solid foundation for Keys-based action. The keyword is resilience.
9. Local government is an important part of the solution, setting local targets, coordinating local initiatives, pushing state and national action from “below”, and generally helping to secure that the effort to build up resilience remains “climate-smart”.
10. The Keys economy must remain viable if the community has any chance of thriving. Sixty percent of the economic activity comes from tourism, with no substitutes in sight. Tourist activity has been shifting from nature-based activities to historical tourism based on Key West. It is important to eliminate any dissonance between communities and induce maximum cooperation in their mutual interest.
11. Although mainly applied to the marine ecosystem centered on the coral reef, resilience is also a vital survival factor for other parts of the Florida Keys “super-ecosystem” – relating to natural areas, native species populations and human communities.
12. Structural change threatens the resilience of the human community in the Keys, with an influx of occasional visitors owning local property but having no other local interest. It is vital for survival to retain the strong current sense of community that remains. One way is keeping the young on side through education and outreach, encouraging them to stay, and to enlist their help working with and educating the older generation.

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# APPENDIX 1: KEY ISSUES FOR THE FLORIDA KEYS

## CLASSIFICATION OF PERCEIVED KEY ISSUES FOR FLORIDA KEYS



## HARD-TO-SHIFT FORCES

### 1 CLIMATE CHANGE

*All the workshops saw climate change as the underlying force. The various forces listed under climate change reinforce and interact with one another (such as warming and ocean acidification) but other external forces also show interdependence. For example, salt water intrusion is listed under sea-level rise as well as under water supply, reflecting the fact that the various effects of climate change exacerbate the impact of economic and demographic growth on the availability of water. Similarly, climate change and lack of pollution control are jointly responsible for coral health and loss of resilience.*

***Warming***

- Impact on coral health – bleaching (accompanied by a range of other marine diseases)
- Coral bleaching hit the Atlantic first (12 years before it hit the Great Barrier Reef).
- Loss of coral cover, especially shallow reefs
- Loss of endemic species of plants, wildlife and invertebrates
- Invasive species taking over ecological niches. Algal blooms.

***Sea level***

- Rising much faster than projected; could flood most of the Keys
- Salt water into Biscayne aquifer
- Low-grade sewer systems – insufficient to deal with sea-level rise

- Need for better stormwater and wastewater treatment in Miami-Dade, Broward and Palm Beach
- Declining conditions for birds and fish at low tide

***Ocean acidification***

- Exacerbating the impact of warming along the Keys

***Hurricanes – more of them, or just more intense?***

***Other***

- Increased threat to fisheries
- Threat to real estate values
- Climate change deniers/skeptics still delaying action

## 2 WATER SUPPLY

***Biscayne Aquifer:***

- Florida Keys Aqueduct Authority managing the aquifer
- Intrusion of sea water, especially if sea-level rises
- Water becoming limiting factor for development
- Cumulative effect of drought in South Florida

***Alternative sources are expensive:***

- Treatment of wastewater in Miami-Dade County (mainly non-potable)
- Reverse osmosis technology may bring quality up to potable

***Local remedial action:***

- Rainwater cisterns coming back in; residents converting septic tanks to water storage systems
- Some homes provide all their own water needs
- Solar energy
- Other technologies if viable

## 3 CARRYING CAPACITY

- Carrying capacity study 2002: key document
- Based on endangered species model (hammocks connectivity, Big Pine endangered species)
- Rate of Growth Ordinance (ROGO): limited building permits, building heights
- County 2010 Comprehensive Plan: Tier system

***Population consequences:***

- Just too many people (locals and visitors) for too small an area
- Losing our workers, and volunteers
- Few young people return to work in the Keys
- Population projected to double in size in Florida by 2060
- Discriminating between types of residents and visitors to attract
- Litigation costs high if trying to prevent people from coming here
- Keys may become almost entirely populated by the wealthy
- Transient community – people living here part-time only

***Special issues in Key West:***

- Dilution of unique heritage through unbridled development
- Drastic community change could happen
- Newcomers' lack of understanding of heritage

### 4 External influences

- Offshore drilling threat from Cuba, especially to Tortugas
- Red tide from Mississippi, runoff; flooding Ohio and Mississippi Rivers; algal blooms in Gulf
- Pollution from Florida sugar cane industry expanded for biodiesel
- Stormwater from Everglades
- Pressures from densely populated Counties to the north
- South Miami/Dade development projects
- Cannot control ocean outfalls to the north (Keys deals with its own waste)
- Harder to organize hurricane evacuation if roads north can't handle capacity
- Opening up of Cuba: opportunity or threat to Keys tourism?
- Competing with Cuban dive spots
- Opportunity to cooperate on ferry and air transport
- Share destinations.

## ISSUES THAT CAN BE MORE READILY INFLUENCED LOCALLY

### 5 Reef health, sustainability and fisheries

***Main underlying issue: climate change***

- Major factor: warming

- Can act locally – main long-term factor environmental sustainability
- Work on coral resilience, sanctuary development
- Restoration of *Diadema* sea urchin as lost member of chain keeping ecosystem healthy
- Restoration of elkhorn and staghorn corals
- Reefs more vulnerable than GBR due to proximity to coast
- Reef health vital to reef use, including fisheries
- Great deterioration already observed since 1950s-1960s
- We all need to get on bandwagon to promote reef health, like GLEE and SFFFK

***Water quality***

- Keys acting as turbidity barrier
- Pollution from cruise ships
- Everglades restoration essential for fisheries and drinking water supply

***Fisheries***

- Division of fish stock between commercial and recreational fishers
- Access problems for commercial fishers due to rich recreational fishers
- Commercial fisheries strictly regulated. Recreational fishers are not
- Need to educate commercial fishers how to conduct good businesses
- Overfishing – declining fish size
- Long-term increase in fishing pressure even if current recession may provide respite
- Excessive technological use (GPS)
- Zoning and increased yield in unprotected areas
- Environmental damage from hurricanes – lines trapped around coral
- Prop-dredging, anchor damage – reef 'death from a thousand cuts'
- Support fishing but limit damage to sensitive ecosystems and reefs
- Monroe County is a major commercial fisheries area

## 6 POLLUTION

- Mandate to put in sewers
- Sewerage progress in Monroe County running behind mandate
- Monroe County stormwater control
- Coral bleaching, associated disease history, and land-based pollution and other influences
- How to maximize coral resilience

- Outfalls to the north mandated to shut down by 2025, but funding is a problem
- Pollution from external sources – major mainland rivers
- Turkey Point Nuclear Station expansion standards
- Water supply is again seen as the limiting factor for growth and development
- Composting toilets use no water and provide compost
- Use grey water for irrigation

***Government management issues***

- Is particular mandated government spending becoming irrelevant with climate change and sea-level rise?
- Allocation system for new residential developments determined by 24-hour hurricane evacuation time rather than environmental issues
- Inequities in application of stormwater runoff rules
- Lack of federal funding for authorized projects
- Support of sustainable building standards such as use of solar energy
- Lack of government incentives to use appropriate technologies
- Key dependence on wastewater treatment in Miami-Dade, and on own investment in Monroe County
- No growth in funding for Sanctuary budget

## 7 ECONOMY, TOURISM, AND DIVERSIFICATION POTENTIAL

***Economy***

- Affordability of living in Keys
- Lack of professional positions
- Boom and bust endemic
- Bussing people in for mundane positions
- Economy has gone 'full-time' last 25 years
- Big threat in polarized wealth distribution
- Carrying capacity – does sustainable growth equal redevelopment while protecting our natural areas and achieving efficiency of energy and water use?
- Role of ROGO and land use plan
- Role of military in economy
- Energy crisis and potential of alternative energy
- Importance of people living with alternative energy in No Name Key

***Tourism***

- The economic engine – we are a tourist economy, first
- First-class restaurants scarce
- Hotels out-pricing tourist market
- Transition to upscale economy but lack of upscale services and facilities
- Getaway destination for millions from Miami
- Rising fuel prices will deter long-distance travel (both road and air)
- Lack of workforce to service tourist resort economy
- Cruiser destination, and implications
- Key West special – historic buildings and culture

***Cultural change***

- Rising property values, locals able to sell at high prices (especially waterfront)
- People moving in buying to resell, or wealthy buying 3rd or 4th homes, including Europeans
- Loss of people who want to improve the community
- Lack of emotional investment
- Attract people who are concerned about Keys community and environment
- People who can live and work here full-time
- Preservation of lifestyle associated ultimately with reef

## 8 EDUCATION AND OUTREACH

*Controllable by providing more/better education and outreach*

- Education – communication – enforcement
- Alleged lack of law enforcement
- Strengthen boat license conditions
- Encourage environmentally aware tourist attractions
- Education-based and ecotourism
- Ecotourism education center backed by educational institutions
- Programs like Green Lodging; involve guests as part of solution; good for business too
- Educate people on the success of things
- Educate locals in sustainable behavior in community's interest
- Educate local as well as visiting boaters on limiting reef damage
- Problems educating people from diverse cultures, especially older people

- Use children to reach the parents
- Involve people already here (dive industry, FKNMS) in educational effort
- People leading by example such as GLEE
- Promote recycling campaigns
- Promote alternative energy – local use; biodiesel for boats; solar panels; tie to global change
- More efficient promotion of no-take areas
- Anticipate impact of climate change (warming, sea level) to help build resilience
- Adopt a long-term planning view
- Learn from past mistakes

# APPENDIX 2: SCENARIO-PLANNING WORKSHOPS

## INTRODUCTION

The five scenario planning workshops in the Florida Keys in June 2008 were recorded verbatim and proved a rich source. Participants were sent a preliminary list of main issues in October 2008, and again in June 2009. Further analysis shows that there are two types of issues though there are clear overlaps and connections between them:

1. **Primary issues (hard-to-shift forces):** climate change, water supply, carrying capacity, and external pollution and other influences from outside the Keys. The primary issues are described from the workshop proceedings in Sections 1 to 4 below.
2. **Issues under potential local control**: reef health, sustainability and fisheries; pollution control; the economy, including tourism and economic diversification; and education and outreach. See Sections 5 to 8.

The five workshop locations are listed from north to south (Key Largo to Key West).

## CLIMATE CHANGE

### KEY LARGO

***Sea-level change and climate change***

- There is a projection that 80% of Monroe County will be under water by 2060. What would happen if such models prove increasingly accurate?
- And what happens when the threat of global warming becomes more apparent to people than it is now?
- Need to start planning for such eventualities just as hurricane planning is now practiced.
- Such a worst-case scenario would keep depressing real estate prices, which will make it more affordable in some ways, but it also makes long-term residents' houses harder to sell. In the short term, with a mortgage requirement to insure what the insurance company dictates to you how much compared to what you want to have is becoming a huge issue. Many are paying ten grand for all their insurances, but only $1,300 in taxes.

### ISLAMORADA

***Climate change is the fundamental issue***

- The Keys are so dependent on the environment, which is the reason people choose to live here and visit here.
- The climate also produces the natural resources needed for development, including fisheries; threatened under climate change.
- Further threats from ocean acidification to coral, calcareous algae etc.

- Many still think climate change is not real.
- We have to figure out ways in which we can either adapt to it or hopefully stimulate the prevention of climate change through our own efforts, but it's a worldwide problem.

## MARATHON

### *Climate change and sea-level rise*

- Dramatic changes in coral cover and attractiveness of reefs over the past 40-50 years (two older members of the workshop)
- "Wild cards in the deck." How much, how fast over how long a period? Maybe not a concern to us, but to future generations. "It would be devastating to the economy of coastal states, in particular the Florida Keys." On our infrastructure even with small rises, sewage etc, and putting salt water intrusion into the Biscayne aquifer.
- "You know, it's not going to take much to start shrinking our little piece of paradise."
- "From the standpoint of the impact on real estate values. I mean, as soon as it's predicted and predictable that it will happen, if in fact it does, I would think our real estate market in the Keys would just go into the toilet. No pun intended here."

## LOWER KEYS

### *Climate change*

- Seven or eight of the ten hottest years on record during the past decade. If that continues we are going to continue to see the impacts of those hot conditions on our coral reefs, on the other marine life, even on ourselves eventually.
- Thirty years' observations of the effect of climate change on our coral. Great Barrier Reef (with whom FKNMS cooperates) only saw first bleaching event in 1992. The Pacific in Australia has been running about 12 years behind what's happening in the Atlantic, and we're at greater risk here because of the small size of the wider Caribbean basin and the low diversity we have in corals.
- Prognosis: continued acceleration – coastal resources being affected in different ways by fish die-offs, harmful algae blooms, all triggered by high sea surface temperatures with a great deal of additional microbial activity as a result of this increased intensity. Corals will respond to this even in areas now considered resistant or resilient.
- New report by The Florida Coastal and Ocean Coalition looks at climate change around the State of Florida and the potential impacts. Not just climate warming two degrees since 1960 but sea-level change – things likely to change more radically than corals. But regarding corals, the report found that water quality is an exasperating parameter with climate change, and one recommendation is to improve both storm water and wastewater treatment as in Miami-Dade, Broward and Palm Beach County of removing in the next 14 years 600 million gallons of poorly treated sewage that goes out on those reefs every day.

- With climate change because of temperature changes and shifts, there's a shifting in species, non-native species moving in. Here in the Keys you probably could expect more tropical species coming in from the- Caribbean. Also introduced Australian trees which proved pests (*Casuarina*, *Melaleuca*) will move north.
- We can completely lose endemic species of plants, wildlife and invertebrates to climate change, either through direct or secondary impacts. And species like iguana [and lionfish?] taking over ecological niches.
- Jury not out on whether climate change will bring more or less hurricanes.
- Dry Tortugas has much more coral cover than the Keys reefs. There are four different reef types in the main Keys: The shallow group reefs, the deep reefs, the hard bottom habitats and the patch reefs. The shallow reefs, like the ones that we all go to, are the ones that are showing the greatest amount of decline. Prior to 1997-98 the coverage was about 20%. In 1997-98 we lost 30% of those shallow reefs. Now it's been stable since '98 with just a couple of drops in the hurricane years of '05, '04, '05.
- The patch reefs stayed stagnant and they've come up slightly in coverage, but in the Tortugas where we have the Tortugas Ecological Reserve, we have between 40 and 60 percent living coral on all of those reefs. And those are a fully protected area where activity is minimal to keep them in reserve, because that's upstream of the Keys and anything spawning there comes in this direction.
- Sea-level scenarios, (Harold Wanless, University of Miami). Alarming implications for the Keys.
- Sewer systems are engineered at a very low grade, and just a minimum amount of sea-level rise will start backing up sewers in major cities. We're talking about a decade or two – very short time frame (coastal North Carolina, Tampa, St. Petersburg used as examples).
- Decline of great white heron and its sensitivity to water levels at low tide. Also fish in the flats area such as bonefish.

## KEY WEST

***The environment is our livelihood***

- "Climate change and global warming. This is very serious, but yet we have responsible people today just pooh-poohing that idea."
- Tide is changing quickly with documentation of what was projected to happen in 20 years now happening in two or three.

# WATER SUPPLY

## MARATHON

***Water supply***

- Florida Keys Aqueduct Authority supplies all drinking water from a shallow aquifer called the Biscayne aquifer. Main concern: intrusion of sea water
- Threat from atmospheric conditions – drought
- Another threat to water is climate change and the potential for elevation increases in the sea, which would push salt water further in, which could contaminate the Biscayne aquifer
- Florida Regional Planning Council (Broward, Monroe and Miami-Dade County) now requires in all comp plan amendment proposals that you address water supply because it is becoming the limiting factor from the standpoint of development
- West Palm Beach, Broward and Miami-Dade are recognizing that they're will have to go to advanced wastewater treatment because they've been dumping throughout falls millions and millions of gallons of water every day
- Already recognized in the northern parts of Florida, southern parts of Georgia, lakes and rivers that used to exist are dry now. "Water is the new oil."
- Desalination plants in Key West and Marathon capacity to supply 1 million gallons a day in emergencies (at four times the cost of normal water) compared with total consumption of 17-20 million
- Reverse osmosis (RO) process getting cheaper. Freshwater lake at Ocean Reef Club (Key Largo) water golf course cheaper than available from Aqueduct Authority (but not potable)
- Treated wastewater mainly non-potable.
- Miami-Dade County only has 5-6% of treated wastewater. They dump most in the ocean. Will have to spend a lot of money on advanced wastewater treatment
- Key Largo was planning to improve RO technology to bring treated water up to potable
- Tampa has found that using RO has changed the chemistry of the Bay – more salinity affecting marine life
- Problem with RO: need for finer and finer screen and bigger pumps and lots of energy to push water through.
- Solar mentioned as possible energy source.
- Monroe County using not only Biscayne aquifer but also deeper Floridian aquifer with more salty water – using up 5% of total during busy season considered safe. Aqueduct Authority also building a low level reverse osmosis treatment plant on location at our well field, with which we will be tapping the Florida aquifer. But it's not as energy intensive as salt water. So we are looking for alternative sources. And the governing

board had to advance the capital spending on that by six or seven years from their original game plan because of the cumulative effect of drought that affects all the southern part of Florida. But the problem is wherever they stick the straw in the ground, they're drawing from the same common shared pool. So you can use reverse osmosis, but somebody's still going to pay for that.

### LOWER KEYS

#### *Water supply*

- Water quality and climate change, see above.
- Threatened by droughts affecting Lake Okeechobee and continued development in Miami-Dade and Broward Counties.
- Also threatened by new tower at Turkey Point nuclear station consuming water from Biscayne aquifer, within next 10 years.
- "In the early days the people in the Keys had cisterns in which they stored rainwater, and then when they built the pipeline to the mainland trying to get the water steady, then the cisterns were destroyed as part of the mosquito management thing, but now we're going back to cisterns."
- "People are beginning to, of all things, change their septic tanks into water storage systems. And there are a few homes here in the Keys that actually provide all their own water, including their drinking water, and I think we're going to move toward that. Put that in your best case scenario."

## CARRYING CAPACITY

### KEY LARGO

#### *Population*

- The people we are losing in a declining population are the worker bees who worked in the community, also as volunteers
- According to two young women professionals in the group, few young people return to work in the Keys, especially graduates who are not paid what they can earn elsewhere (though graduates from Coral Shores High School seem to return in greater numbers).

#### *Carrying capacity*

- Based on the built system and the natural system. How many more structures can we have within the Florida Keys and still maintain. We're in a state area of critical concern to maintain the connectivity of the hammocks, and the Big Pine area for the endangered species. It's all based on an endangered species model.
- We have limited rate of growth ordinance, limited amounts of building permits that we give because they saw that the Florida Keys was a sensitive habitat. We have limited

heights of our buildings so it doesn't become a mini Miami Beach, which could have happened if the Keys wouldn't have changed that back in 1985.

- Maybe what needs to be looked at is the transient community, how many people that will not live here. Maybe that should be capped, because there is no cap on that.
- The reason why they're talking about tying the carrying capacity to the number of structures; maybe only 30% of them are fully occupied at any one time, but the fact is those structures still exist, and if somebody came down and lived in those structures we would need this level of service on our highways, we would need this size power generating station, we would need this size pipeline.
- Only about 40% of the structures in Monroe County are homesteaded.

### ISLAMORADA

***Population – carrying capacity***

- Population increase and visitor numbers – too many people in too small a space. "The issue is the increase in population, is the number of people coming in, and right now we're kind of juggling it. You know, we're trying to prevent development of waterfront areas, we're trying to maintain working waterfront areas and usage, but eventually, whether we're looking at 20 or 50 years in the future, there's going to have to be some kind of restriction or some kind of control over population growth and development to be able to maintain the character of the Keys, assuming the Keys are still here."
- Carrying capacity (locals plus tourists).
- "The issue that comes from there is both in Monroe County and here in the Village there are a certain number of permits that we give out for new houses. You can buy a house, tear it down and rebuild it, but to add a new dwelling unit, we have to account for that somewhere. Even to add nonresidential square footage, you've got to account for that somewhere. And there is a limit, and it's, I believe the Village has extended it to 2020." But what happens after that date?
- The Keys may be entirely populated by the wealthy.

### MARATHON

***Population – carrying capacity***

- Carrying capacity study was to measure whether we are in a sustainable situation or not
- "In light of the reduced fish, loss of habitat, the pollution impacts from agricultural run-off, and a host of other things, … I think that it's a good thing that we're slowing down and maybe it will bring us back into not a worst case scenario but a sustainable situation."
- We couldn't afford the litigation to keep people from coming here based upon numbers and/or building their properties. State should (but isn't) use the economic downturn to buy land at the lower prices

- “One result of the carrying capacity study was a court order mandating a work plan and changing the County 2010 Comprehensive Plan in various ways. One of the big results was the tier system. And also setting aside that certain sized parcels are more sustainable in protecting the environment and therefore more valuable to the environment as a sustainable parcel of land. And then you got more negative environmental points about building on there and whether road counted as a break in the environment, etc. So there were specific results that changed the comp plan as a result of the carrying capacity study.”
- [Also see http://www.monroecounty-fl.gov/pages/MonroeCoFL_HotTopics/tiermaps]
- Loss of multi-generational handing over of businesses.

### KEY WEST

***Population growth***

- Keys is downstream from rest of Florida which is expected to double its population by 2060.

***Development***

- Disappearing waterfront.
- Unchecked development diluting unique cultural historical element in Key West.
- Up-scaling of the community may benefit individual businesses, but doubtful community benefits.
- Doubtful that long term will be sustainable in Key West, with drastic community changes.
- We may not like it, but change is probably unstoppable, natural progression, and ‘we haven’t become Miami’.
- Fifteen years ago we wanted better quality (richer) rather than more customers, now we complain it is killing the life blood of the Florida Keys.
- Development of upscale condominiums on waterfront. Senate study: short-term positive but long-term negative.
- “Because that's all that is, it's all just about greed and money, because they're not concerned about the impact on the environment and they're not concerned about changing the cultural aspect of wherever they build. There must be real big fast money on the front end.”

# EXTERNAL INFLUENCES

## KEY LARGO

### *If Cuba opens, and oil drilling*

- Loss of ports that could handle Miami River little freighters and repairs. Loss of boating infrastructure. Loss of dockage in South Florida for boats 100+ feet long. Bought up by those buying $4-5 million homes. Dockuminiums. Stock Island.
- Boot Key Harbor opportunity – safe dockage and facilities.
- Offshore drilling threat in Cuba – opposite Tortugas. Real threat.
- Drilling also huge threat in Alaska. And apparently permits exist in Everglades.
- Red tide from the Mississippi
- Penetrated from Louisiana, Texas, round the big bend to Tampa, eventually to Key West.
- Why and where did it come from?

## MARATHON

### *Pollution from afar*

- Floods in the Ohio River, the Mississippi River. The Gulf Stream out there will turn to mud, and you'll be having to troll sometimes 50, 60 miles offshore to find any blue water. Will hit charter boats, burning more fuel, which means it becomes more expensive to go fishing.
- Oil drilling in Cuba
- China has already proposed to help develop offshore drilling, concentrating on the most promising areas, unfortunately on the northwest coast of Cuba. Explorative wells have been drilled. Gulf Stream ensures that oil spills would affect the Keys.
- However, the oil drilling industry has cleaned up its act. "The transportation part of it is where you usually have the problems, the Valdez and moving it through the tankers. But the actual drilling industry has become a very clean industry."
- Uncertain what practices would be used to drill; a very expensive process to extract hydrocarbons from the floor of the ocean or the Gulf of Mexico.
- ANWR [Arctic National Wildlife Refuge] and other areas were disallowed and oil prices are soaring.
- The US economy has thrived on its low fuel prices. Now sales are down in the automotive industry (SUVs etc) and the marine industry is really hurting.

### *Ethanol from sugar cane*

- Brazil became energy-independent 30 years ago

- “You've got up in the central part of Florida a sugar cane industry that would not exist if the price of sugar was not subsidized by this government. At some point somebody instead of wanting to drill in ANWR is going to say, well, shoot, what we ought to do is flood all that land and grow sugar cane and make bio-diesel out of it. That's what makes me nervous.”
- Sugar cane growing in the past 80 years has caused most of the pollution of the Everglades, which affects all the southern part of the peninsula.

## LOWER KEYS

***Pollution and other impacts from outside***

- We are dealing with our wastewater but cannot control the outfalls.
- Catching stormwater from the Everglades.
- Production of biofuels from increased sugar plantations. Increased nutrients being brought down through the Everglades into the Keys are fed by dangerous algae blooms harmful to the reef (see further under climate change).
- Development projects in South Miami/Dade. We share resources with those folks and there's more of them every day. So a combination of the sharing resources and folks vacationing on a weekend down here is going to put pressure on our infrastructure beyond dealing with residents and our regular hotel trade.
- The more people that are in South Dade and Broward counties the more traffic will be coming down here to support the tourist industry. A double-edged sword.
- Political threats or opportunities
- Threat or opportunity: Complete change of government and economic system in Cuba next 10-20 years. Cuba as a possible destination by ferry or air from Key West. Lots of dive destinations around Cuba. This can happen day after tomorrow. TDC has worked on Cuba opening up as a competitive destination. We can’t compete with their beaches but maybe combine Cuba and Keys as destinations.
- Continued and expanded war in the Middle East.
- Biggest threat, however: linear thinking and people that are always going to continue to do things the way they've always done things. Not being educated out of that sort of thinking. Usually older people?

***Hurricane evacuation***

- The more South Florida fills up with people, the harder it is for the people in the Keys to evacuate in a hurricane. Maybe relatively easy to get out of the Keys (despite only one highway so you would have to leave early) but all roads would be clogged with people getting out of South Florida.

## KEY WEST

### *Influences from outside*

- Even in Key West, you only live 175 miles away from 4 million people, and those people are going to continue to come down here on a regular basis, maybe not to the degree that they have in the past for whatever reasons
- "We can't control living downstream from the Gulf of Mexico, from the Tampa agricultural areas and the runoff and the algae blooms. I don't know how we deal with that other than the state making all these other areas terminate their outfalls and go to advanced wastewater treatment like the Keys are going to, but I just am very optimistic about what will happen in the future."
- "The sea-level is coming up, temperature is going up, but all we can do is work to reduce our emissions which are the primary thing that's causing those things, and then work on removing some of those other cuts, destructive fishing gear, prop dredging, maybe sun screen on the reef."

# REEF HEALTH, SUSTAINABILITY AND FISHERIES

## KEY LARGO

### *Reef health and fisheries*

- State of natural resources is the bottom line (reef health; no one would come if no fish).
- We can do things locally, especially on fishing, despite international nature of coral problem.
- Problem not just a result of climate change.
- While coral problem is global, we can act locally: identify areas of coral more resilient than other areas, less subject to bleaching.
- Can we connect some of these areas, through corridors, and allow them to recover?
- History of sanctuary development: initial resistance, then acceptance, and five years later special protected areas.
- Despite loss of some species, our reefs are amazing. Little coral cover but beautiful reef structures, lots of soft coral. So we have a beautiful system which needs protection.
- Is chumming for silvertail healthy for the reef and reef fishing generally?

### *Water quality*

- Tumors first in turtles, then lobsters, shrimp, fish, due to connectivity of systems .. water quality problems broader than they used to be. Theory expressed: outflow of organic matter (hormones, pharmaceuticals) from cruise ships and the coast through untreated sewage from septic tanks cause of the problem. Maybe cruise ships main problem because in greater concentration and on the water itself.

- Water quality issue huge: Everglades restoration essential not just for the Florida Bay fisheries but for our drinking water supply increasingly exposed to saltwater intrusion.
- Is the reason why we have so much coral that we do have in the Upper Keys versus Marathon because we don't have as many openings from the bay side to the ocean side? So the islands actually act as a turbidity barrier. It's going to be interesting to see what happens when they open up Jewfish Creek Bridge and take that stretch out, if that's going to affect some of our Key Largo reefs up with opening that up.
- If instead of paving US1 like we have now, it is put on piers like they do in Louisiana over the swamp, the water flow would go. The animals wouldn't be hurt.

***Environmental sustainability***

- The main long-term factor for the Keys.
- It all goes back to the environment, the reef. If we don't take care of the fisheries, the reef, the Everglades, then none of us are going to need to be here because there's not going to be anything going on.
- Three year study of reef resilience in Florida, looking at areas more resilient and resistant to different climate change scenarios, and able to recover from bleaching. People asked to vote on ten strategies for increasing resilience; stringent boater licensing came in as number three. Too easy to get one now, just answering a number of questions; no requirements to know about environmental matters. Any change being resisted by recreational boating industry.
- In 1983 we had our sea urchin die-off, and that was really the initial event that caused the beginning of the demise of what's gone on with the reefs now, and that was when the algae started building up and corals began to die, we saw more diseases.

***Commercial fishing***

- Fisheries management divide fish stocks between recreational and commercial fishers.
- Wealthy buyers preventing access for commercial fishermen.
- Now everyone uses GPS to go straight to the fish (man’s got too smart for his own good). We are a lot more efficient when it comes to harvesting.
- Commercial fishing saved the Keys for a long time; recreational fishing grew from the mid-1970s changing the split of the assets.
- Commercial fishermen have to abide by strict regulations. Tourist rent boats and go fishing without knowing the fishing regulations and the laws, and they pull fish out of the water that should have never been iced and taken home. And they're blaming a lot of the fishing decline on the commercial fishermen.
- The mini-lobster season (two days end of July) is a nuisance. Lots of uncaring Miami people come, reefs get raped, the lobster fishers cheat, injuries happen, no one seems to be in favor.

- 90% of US spiny lobster tail production is in Monroe County, commercial fishing is a $100 million industry but licensing becoming restricted to particular species: lobsters, stone crabs, yellowtails etc. Difficult to get a license without a record of catch or buying someone with a license out. Only a handful of good fishermen also know good business.

## ISLAMORADA

### *Sustainability of the reef is vital*

- The reef is the focal attraction for tourists and for people living here.
- The coral reefs have an economic value to tourism between three to six billions of dollars dependent upon the base used. And the reefs are also the basis for the fisheries. While the whole ecosystem is under pressure, the coral reefs are central.
- Ocean acidification, sea-level rise, more intensive hurricanes destroying Keys infrastructure, small but finite risk of tsunamis which could hit the Keys despite protection by the Bahamas.
- "In a coral reef all throughout the Caribbean, the Bahamas, the Florida Keys, there's a balance between the growth of algae and the growth of coral, the balance that is controlled by herbivores." Since the 1983 plague destroyed almost all the herbivorous sea urchins (Diadema), the coral reefs have declined precipitously (not the only reason for the decline in coral reefs, but a significant factor). Program at Mote Laboratories to restore reef resilience through reintroduction of Diadema. The current reef structure will allow coral to come back if herbivores are returned to eat the algae.
- Vulnerability of reefs due to proximity to Keys (much closer than the Great Barrier Reef to the Queensland coast).
- "The grouper is a long-live fish and the intensity of the fishery on it prevents them from really developing. So over-fishing is a very critical, and we're trying to control it through the Fishery Management Councils and through the Fish and Wildlife, the laws and regulations. And many times these are flouted, because people look at short-term commercial gain over long-term resource sustainability."
- "This is where education comes in, and with recreational fishermen, too. Like even the lobster fisheries, the microcosm of what happens throughout the world here. You have people that do everything that they possibly can to flout the resource laws that are in place now. You know, they double-trip out and are harvesting lobsters out of season and short lobsters in tremendous numbers."
- Cross purposes between diving/snorkeling and fishing – over-fishing; decreasing fish size.

## MARATHON

### *The reef and water quality*

- Economy revolves around the reef and the water quality

- Perspective on reef deterioration since 1950s. Stoppage of water flow from the Everglades (C-111 Canal) – program undertaken to support growth of Miami and Palm Beach/part of Everglades restoration plan. Algal blooms in Florida Bay. Hyper-saline water in Bay aggravates coral bleaching etc.
- "In the early '60s, late '50s, I would dive off of Elliott Key and all the way down to Carysfort, and it was just covered with elkhorn and staghorn coral. It was really pristine. I can remember swimming in the salt water pool at Hall's camp and around the rocks there was hundreds of lobsters."
- Diadema, critically linked to reef health because it forages on algae. Lost member of the chain that keeps things healthy
- Restoration of elkhorn and staghorn corals (Nedimyer)
- Elevation of water temperatures is the major factor causing reef deterioration worldwide, including the Keys
- Some promising signs of good coral cover: Duck Key, Hawk's Channel
- If we can get a status with the population and tourism where we were ten years ago, it could be little less impact on the reef.
- No human waste found on the reef [but University of Georgia research (James Porter) found massive death of elkhorn coral caused by enteric bacteria (*Serratia marcescens*) which live in humans and other animals, and can also survive as a free-living microbe in both water and soil). (http://www.scienceblog.com/community/older/2002/B/20026007.html)

***Fishing***

- Amberjacks disappearing from shallow waters
- Fishing pressure dropping off due to fuel prices and the economy
- But compared with 1950s great increase in fishing pressure
- Fishing regulations, e.g. closures for snapper/grouper, use of circle hooks etc [on hooks, see http://www.magazine.noaa.gov/stories/mag144.htm - protection of sea turtles?]
- Number of people coming to the Keys with improved technology from the standpoint of fishing. GPSs that will put you on all of the lobster holes [Global Positioning System]
- No-take preservation areas have helped to increase fish stock in those areas. More should be added, and it is safe to assume that the Sanctuary is always looking for more areas. A lot of people on the Sanctuary Advisory Council feel like that we haven't shut down enough areas for protection areas.
- Has the reef rebounded due the closures in Tortugas where the largest no-take areas are? Tortugas reef in pretty good shape in comparison with other areas. Tortugas was specially protected because it still had a high number of species and the reef in good shape. And they went about it in a very diplomatic way in doing it. A lot of education, a lot of outreach to the general public, both recreational and commercial fishermen.
- Tortugas is a national park, not a sanctuary. The mandate there is to protect the species.

- If you can protect the brood stock, you have done something good to continue to fish those species sustainably.
- In the Great Barrier Reef, the yield in the unprotected zones went up significantly when the no-take area was increased from 6% to 30+%. (However, the GBR is huge and much further from the shore than in the Keys)
- Protection has helped increase fish sizes, e.g. goliath grouper, jewfish. Catch and release also helps to protect the fish
- Fish have learnt to stay in protected areas and not stray into the legal spear-fishing area adjacent to Pennekamp and Key Largo Marine Sanctuary. The fish have virtually disappeared in the spear-fishing areas
- Snapper numbers likely to increase due to circle hooks.
- We had two seasons in a row three years ago of very bad hurricane seasons and a lot of commercial fishermen's traps were washed into Hawk's Channel, trap lines got wrapped around coral. Commercial fishermen are worried that traps may be outlawed to protect the reef. SAC however is sensitive to prohibiting as also demonstrated about spongers on the flats ("they have as many rights as flats fishermen")
- Very grey areas. If lobster trap fishing is seen to negatively affect elkhorn and staghorn habitat, hard to know what would happen, because the Endangered Species Act has tremendous reaching ramifications.

## LOWER KEYS

### *Change in fishing attitudes*

- Less "fill my freezer", much more catch and release.

### *Prop-dredging and other damage*

- We keep killing the seagrass beds with ever larger propelled boats; the reefs too. A concern both from the sea-level rise standpoint and the standpoint of people abusing the environment, maybe not wanting to, but inadvertently doing it just because we pack too many people in areas that weren't designed for that many people to maintain the health of the ecosystem.
- "Part of the linear thinking that always drove me nuts was when we were deciding where to allow docks to be built, we knew about the phenomena of prop-dredging. So we said that docks had to be in locations that were at least four feet deep. So what we got was a bunch of boats that were four feet draft, that then proceeded to prop-dredge any place that was less than four feet. We probably should have said no docks allowed in any water deeper than three feet and then we would have gotten smaller boats and less prop dredge."
- "The mooring, absolutely, every time I go out there and throw an anchor over I'm tearing up the bottom. It doesn't make me feel good to do that, but I think it really needs to be looked at."

- Fixed gear fishermen leave debris and damage the reef and sensitive ecosystems. We want to support fishing in our community, but the type of fishing does significant damage.
- Mangroves full of neat little balls made of Styrofoam.
- The FKNMS maintains over 480 mooring buoys, most of them focused on coral reef areas, but some in seagrass areas, and over 500 marker buoys that mark the zones and the management areas, sanctuary areas and so on, and that marking costs nearly a half a million dollars a year to maintain.
- "We heard about prop-dredging and anchor damage and destructive fishing, the death by a thousand cuts on the other side, and it's really going to take a million different fixes to fix the thousand different cuts on the other side. We're all going to have to get on the bandwagon. We're on it already. Look at the success of GLEE, Green Living and Energy Education group here in the Keys. … People are starting to become willing to make those changes and here we are picking up speed."

***Sustainability***

- Keyswide Sustainability Project (under GLEE) specifically pulls together the major policy makers here in the Keys. All six local governments plus our three major utilities have been meeting together about quarterly. Almost all major fleets are in 20% biodiesel now, and that's mostly because people sat in the same room together. Helps tally all your emissions and places where you're wasting the most money or resources so they can step-wise work towards fixing it.

## KEY WEST

***Fishing generally***

- "If we took away the recreational activities, the commercial fishing, there really wouldn't be the community as we know it today."

***Commercial fishing***

- Tourism is the juggernaut of the economy but commercial fishing is by no means dead.
- 800-900 permitted vessels with 2-3 crew each suggests that 5% of residents are directly involved in commercial fishing, bringing in $100 million or more a year.
- To reduce human impact on the environment fewer people should be catching the same amount of fish making more money and being more upscale, professional fishermen.
- Without Monroe County, the South Atlantic Fishery Management Council would have very little to manage: County accounts for 40% of all federal snapper/grouper permits from Georgia to Key West, and catch 35% of all snapper/grouper. Similar with other species.

***The environment is our livelihood***

- Everything revolves around the environment.

- Sustaining the environment both globally and locally.
- How to adopt policies to establish preservation as a community.
- Lack of control by community, county, over State of Florida capacity to sustain itself.
- The key is sustainability: sustaining our everyday life and the environment.
- Sustainability depends on water and energy.

## POLLUTION CONTROL

### Key Largo

#### *Pollution*

- We are not recycling any more: we throw it in the landfill
- Getting rid of the septic tanks should help us with the porous limestone
- We are mandated to put in sewers within a certain time
- Thirty years ago, the solution to pollution was dilution. Dump it in the ocean, as still happens off Miami, Fort Lauderdale and West Palm Beach, 300 million gallons a day. Draft legislation to terminate practice by 2025.

### Islamorada

#### *Pollution control*

- Sewage and other pollution. Outfalls mandated to shut off by 2019, but "no money so there are problems."
- Pollution from external sources – major mainland rivers. Some of the greatest negative impacts that occur not only on our coral reefs, but also throughout the Gulf of Mexico and even the Atlantic coast is the discharges from our rivers, from the Mississippi, for example. The farmer in Indiana is contributing to our problems, but he doesn't realize that. So there has to be a way in which the entire ecosystem is addressed.

#### *Government management issues*

- Misdirected government spending because of mandates, becoming irrelevant with climate change and sea-level rise.
- The allocation system for new residential developments is determined by 24-hour hurricane evacuation time – cap on total building permits – rather than by environmental issues.
- Apparently inequitable treatment by planners/regulators: mitigation for stormwater runoff to protect seagrass etc appears not to apply to everyone. "We try to mitigate for stormwater runoff. 'Well, my neighbor doesn't have it.' Well, maybe your neighbor did it without permits or maybe they ripped their grass out. I think it's a lot about education and making people aware that you moved down here for the character, you moved

down here for the reef, you moved down here for the fishing, but if you don't take a proactive step in addressing what you put out, whether it be the actual pollution or your footprint that you're leaving behind, you don't change that and think about the way that you're living your life, then it's not going to be here, period."

- State influence on local planning; push to have all local governments adopt water-planning and land-management standards by August 2008.
- Controlling development of waterfront areas.
- No grey water program.
- Sewer outfalls and unfunded mandates.
- Lack of federal funding and falling property taxes.
- Lack of public transport (but would the locals use it?).
- Public v private ownership - high government ownership of the Keys (95%?). [Carrying capacity study says 70% of the land area. HHG]
- Sustainable building standards (solar etc). "Solar is huge." "I think we'd be a great user of solar, not necessarily a manufacturer, but you need to use petroleum energy now to build the solar panels while we still have the oil so that eventually we can start using the solar."
- Lack of government incentives to use technologies. "The interesting question is not what technology can do, but whether we can make public policy environment let us make use of that technology. If you look at aviation, there's a lot of great technologies that could potentially solve problems, but unless we get to the point local governments and state governments will allow those things to happen, create great incentives to use those technologies, we're not going to get there."

## MARATHON

### *Wastewater*

- Mandated by State of Florida to invest $3 billion in infrastructure investment in Miami-Dade alone. That investment has to happen to preserve the environment in the Florida Keys and our economic base. And even here in the Keys we're putting in wastewater systems to the tune of 800 to 900-million dollars. Paramount that it happens.

### *Pollution*

- Turkey Point nuclear station being expanded. Using bay water for cooling but where does it flow from the cooling canals: into the ponds "right here". [Where? "A separate supply of water that cools the turbine steam supply for reuse comes from a unique system of 36 interconnected canals. The canals act like a giant radiator to cool the water in a two-day, 168-mile journey before it is circulated back to the condenser for reuse." Wikipedia]
- We're mandated by the State of Florida to treat to the strictest standards at least for the moment for the State of Florida, to advance wastewater treatment levels which has to

do with the amount of nutrients within the wastewater. The two main concerns are phosphorus and nitrogen that need to be reduced to as low a level as possible because they may have a degrading effect to the near-shore water quality. And so we're mandated to do it at great expense; deadline 1 July 2010.

- Miami-Dade, Broward and Palm Beach have to end by 2025 for their ocean outfall. So they have between now and then create to replace the aquifer?
- Problems with canals and septic. Observations that fish disappear behind trailer parks with cesspits or septic tanks. Canals were dug too deep and have no tidal flow, causing eutrophication. With oxygen levels far too low, more population and more pollutants contribute to the lack of fish
- Sewerage progress: Key West is fully sewered (problem there is stormwater runoff), Key Colony sewered for 25 years, Layton just got them, North Key Largo is close, problem is unincorporated areas with 70% not done. Mandated to finish by 2010 – running behind.

#### *Stormwater*

- Monroe County is working on right now in conjunction with other agencies, specifically Department of Transportation, to control storm water, and any new development has to address storm water runoff. Many people believe that storm water is just as guilty of polluting and degrading our near shore waters as wastewater is. Will take long and cost hundreds of millions of dollars. With the new 18-mile stretch area with the new bridge up at North Key Largo, D.O.T. addressed a lot of the storm water runoff.
- When Henry Flagler built the corridor viaduct up there, he basically blocked the natural tidal flow that took place from the gulf side -- throughout the whole Keys.
- Examples of creating improved tidal flows through low-throughs and building of culverts: Key Colony Beach, Boot Key Harbor, private projects in Lower Keys.

### LOWER KEYS

#### *Coral bleaching and disease history*

- First big signal in 1980 when we had a six-week period of slick calm weather patterns, we had a massive fish die-off from the reef. 1983: first Keys-wide coral bleaching event, 1987 a Caribbean-wide, and then in the West Pacific it bleached a little. 1990: massive bleaching event. It was the first year we lost a lot of corals, the first year it bleached inshore. In 1997 and 1998 we had back-to-back coral bleaching events here in the Florida Keys at a time the reefs were bleaching on the Great Barrier Reef and at the time there were harmful algae blooms in China, off the Northwest, off Seattle.
- That same year we were having fish diseases all around the wider Caribbean that were affecting reef fish like it did in 1980, and it was the year we had fisteria, an outbreak of a micro-organism as a result of land-based sources of pollution getting into the water, probably coupled with pig farming, essentially their waste got into the rivers, and that accelerated temperature caused this microbe to speed up and so the fisteria developed. It was no accident that all of that was happening around the globe at the same time.

- “We can put our finger on what the stresses are, local stresses I'm doing on my boat or I'm doing when I go around the back country. We need to keep a lid on those things to the extent that we can so if there's any hope at all for these systems to adapt and get tougher and get more able to deal with climate change, they'll have that chance.”

***Waste management***

- Is there some way to encourage waste management -- you have to actually pay more than your dump fee to have recycling happen on your property. This discourages recycling which needs to be supported by the county or state to cut down on landfill.

***Wastewater management***

- One thing that would really help for the Feds to finally stand up and contribute their part to the wastewater mandates that we have in the Florida Keys. However, while Congress may have $100 million authorized, it is not appropriated. 20 percent of our nutrients are coming from wastewater, about 20 percent are coming from stormwater runoff. So these are things that we still have to deal with.
- Same thing, if you look at the South Florida Ecosystem Restoration, that's a $12 billion project, yet the state has funded the majority of the progress that's been made on that to date and the Federal Government has not stepped up.
- The Florida Keys Sanctuary budget is operating on a 2001 level and has since 2001.

## KEY WEST

***Water***

- No regulation on the community who should know their capacity for water in a worst-case scenario. Where is the water coming from?
- Next limiting factor to growth and development in Florida, including Monroe County, is water (South Florida Regional Planning Council).
- Source of water for new hotel (say) – limited by amount of water that South Florida Water Management District determines.
- Advanced wastewater treatment needed in Miami-Dade by 2025; they will have to start processing sewer effluent to potable water, or at least water reuse levels to take the pressure off the Biscayne aquifer.
- We don’t have water in the Keys, it’s piped through the Biscayne aquifer. Water is a serious issue that will affect our economy and we must pay attention.
- Composting toilets – don’t require water, provide compost. (GLEE).
- The Keys not as bad as some other places. In mainland Florida, potable water is used for irrigation for landscaping as well as agriculture.
- If you don’t want a cistern, at least use the grey water for irrigation.

# ECONOMY, TOURISM, AND DIVERSIFICATION POTENTIAL

## KEY LARGO

### *Economy*

- Affordability of living in the Keys (with rising property prices etc)
- Currently people can't sell their properties .. opportunity for professionals move back into the community, to buy back into the area at more affordable prices.
- Taxation levels low in Florida compared to other states.
- Lack of professional positions for people. BPW active here because there are not that many jobs available for women in the community. "So they create their own jobs, they begin their own businesses, and they get active businesses going and successful businesses."
- There was huge turnover in the 1980s when large numbers of businesses regularly went broke. More stability in the nineties but now we are losing that stability again. Monroe County has always been boom and bust.
- Need to import people by bus from the mainland to do the sort of mundane jobs people down here aren't taking.
- Fuel and transportation costs. America has planned its whole society on cheap gas and commuting and in the Keys there is no public transport to speak of.

### *Tourism*

- Hotels out-pricing market for tourism.
- Shallow-water sports fishing (tarpon, bonefish) preceded diving.
- "We're so focused on tourism and getting people down here, but once those people are down here, they go and they dive and they don't necessarily take the necessary precautions"
- Bucket fishermen go out on boats or fish from bridges; may sell their catch unless caught.
- Charter boats may tell tourists that they are only entitled to a catch of 'x' – then they sell the surplus at back door of restaurants
- Tourists want first-class restaurants. Middle class disappearing from Keys – so we don't have the resources to supply these services.
- We need a monorail right down the Keys, elevated with lots of stops.

### *Cultural change*

- Rising property values causing many locals to sell out at high prices, especially for waterfront property.

- People moving in either buying for investment to resell, or very wealthy people buying third or fourth homes, and Europeans buying.
- Swelling out is affecting school and other infrastructure systems in the Keys.
- Loss of people who don't just work here but work in the community to improve the community.
- New people just don't care but just come when the weather is nicest. No connection, no emotional investment. "I'm not sure if the people who are coming down and buying these $5 million homes on the water really give a rat's behind about the coral reef at all." No respect for the area.
- Respite now due to collapse of house prices (but this is causing other societal changes).
- Immigrant population and newcomers, even newcomers to Florida from the rest of the states don't take the time to learn the local rules or regulations and just come down and do their thing with total disregard for any kind of norm or manners or respect. The taking attitude.

***New business opportunities***

- Tourism is our one-legged stool
- Keys started with pineapple plantations, killed by Flagler who started importing from Cuba
- Medicine – University of Miami special cancer unit
- Marriage between marine environment and marine science programs
- We are a living laboratory for climate change.
- Boat building and school to teach boat building
- The arts and exploiting the Internet to develop new businesses ("doing playbooks for Broadway plays")
- Artists' market
- Using affordable housing and existing infrastructure to attract people coming here to study
- Hands-on learning for people who learned from books.
- Important to attract those who are concerned about our community and environment rather than Costa del Sol and the Azores.
- Need to do scenario planning in a structured environment: Where do we want our community to be? What do we want our economy to look like? Something that's stable year-round. We want people to be able to live and work here and prosper here 12 months.

***The Keys as leading indicator for the State of Florida***

- Affordable housing was first a problem in the Florida Keys and then moved up through Florida. Wind insurance was first a problem in the Florida Keys and then moved up the coast and then throughout Florida. Global warming is going to affect us and move right up the State of Florida. We're a very important benchmark to the whole state. It normally happens here before it happens to the state. There are likely to be other examples.

## ISLAMORADA

***Threats to lifestyle***

- Compatibility of environmental change and need for economic diversification.
- Preservation of lifestyle associated ultimately with reef.

***Scenic highway***

- Developing US 1 as a scenic highway.

***Economic diversification***

- Diversification is not incompatible with addressing climate change. Primary concerns are economic diversity, infrastructure, and lifestyle (which is closely related to the reef). It is important that the character of the community is retained.
- Biodiesel from algae. "Of all the different terrestrial sources of good oil-producing plants that can produce oil for biodiesel, algae trumps them by a thousand percent."

## MARATHON

***The economy***

- Tourism is the economic engine – without it, no economic base.
- Other attractions apart from the reef: great white heron refuge, Everglades, Key West (arts, Hemingway get-together).
- Keys are getaway for millions of people living nearby (Miami etc)
- Rising fuel prices is a long-term issue – likely to stay up (US economy has been conditioned to live off cheap fuel)
- Most impact on long-distance travelers, both by road and air
- As well as tourism, real estate is a huge element – State of Florida has lived off real estate transfers, but reduced over past 3-4 years having an impact
- Healthy robust economy statewide equates to a healthy robust economy in the Keys. Increasing number of storefronts closing

- 25 years ago we had a part-time economy ("from Labor Day until almost Christmas you could just about sleep on U.S. 1 without fear of getting run over"). We now have a full-time economy (geometric rise in bed taxes)

***Quality of life***

- One of the largest flyways for migratory birds stopping over – threatened by development. Huge role in the quality of life in the Keys.

## LOWER KEYS

***Florida Keys advantages and limitations***

- The real estate market is not forever dead, because we still have probably 50 years ahead of us as the only American dollar-spending English-speaking primarily tropical Caribbean island, and that will always be desirable to many people who don't feel comfortable investing in a vacation home elsewhere. As long as we are proactive in maintaining the qualities that make us unique, make our scale livable to give us access to the water, that will continue to make us attractive.
- We are a small market and there is a big world out there. We just have to be attractive to a tiny fraction of that market to generate phenomenal values. Several things are important to bring this along: "having a very secure place to live, secure from crime, particularly with elderly in second homes, secure medical and secure property values, and the property values, that comes with maintaining the unique growth control type place." If we lose those three fundamentals, we would lose the transfer payments from the retirees in second homes.
- But we don't have affordability, cost of living, and another threat is growing economic disparity –big threat in polarized wealth distribution. And that's playing out locally. It's very difficult for local people to be able to afford to live in the Keys.
- Waterfront homes in the Keys remain relatively cheap.
- Growth control through the tier system.
- Talking about the economic benefits, retirees come down and work out of their homes, and this has always been an undervalued market. "I'm not trying to stop growth, but there has to be a new way of looking at it .. between the hurricanes, between the economic fallout, lower house prices, rising sea level." Other people in business need to look for opportunities that still exist for them if they're willing to stick it out. They have to look more in the future and not a static, but we can't just keep going the way we're going now. We can't keep growing the economy with businesses and people.
- "The carrying capacity study determined the capacity for the marine and the land base of the Florida Keys to sustain further development, concluding that we had reached build-out in the Keys and that the marine module was difficult to assess because several of the studies actually showed that we had exceeded it, and we did have some decline on our reefs. So the question becomes: does the growth occur in a sustainable manner that focuses on redevelopment of what we have while protecting the natural areas and

improving our use of energy and conserving water and doing things smarter and better so that we can all maintain our quality of life. We need a political mind-set that everybody is part of this. It's doable within the reality of the technology that exists today. It's simply not politically achievable now because not enough people are willing to stand up and support it.”

- This will need leadership by key people in Monroe County and in the State of Florida, as well as bottom-up pressure.
- FIU study (2008) centered primarily around housing, but one of the things coming out of that is we have a very large piece of our economy that's strictly service sector to serve this tourism resort economy that really drives things here, in addition to the military. Over the last eight years there's been a steady decline, in particular the work force, that's been matched by a steady increase of second home market kind of filling in that space. So at what point do you lose the stability of supporting this tourism resort economy that's very high class when you don't have any workforce?
- The Florida Keys has a rate of growth ordinance and land use plan that is one of the most progressive in the country. And that's the reason why that the Keys have kept their character and their rural character.

***Importance of military economy***

- Especially in the Lower Keys, the other linchpin apart from tourism is the military economy. “Something that would really rock the foundation of this community would be a pullout of the military. It would create opportunities. But it would be a significant challenge for this economy and for the culture of this place.”
- Military is big polluter (F-18). The navy, not the army!

***Cruiser destinations***

- The Keys are a destination for cruisers. People actually live on their boats or in the wintertime come down from the north, through the intra-coastal waterways down and spend the winter down here in the Keys, but mostly they go through the Bahamas. So it's much more of a destination for cruisers and a lot of money goes that way, too. The Keys should look at making a cruiser destination here. It would bring a lot of money to the industry -- to the economy down here if it's done properly. With controlled pump-outs, but nobody listens.

***Dredging to allow larger cruise ships***

- So as to go from 3,000 to 5,000 persons per ship.

***Public transportation***

- Keys have very little compared with other major tourist destinations.

### *Energy crisis and alternative energy*

- In the 1974 oil crisis, you could have taken a nap at noontime on U.S. 1. And could that again happen if gasoline prices keep going up? Could be a major hit for tourism, and also for the construction industry. And it's important to keep a construction industry going in the community, not least to cope with hurricane damage. There were big shortages of contractors after Hurricanes Wilma and George.
- "Unless we adopt a renewable energy policy the Keys' economic engine is going to drive to a screeching halt because we depend on drive-down traffic, cruise ships, resorts and vacations with people that have disposable income, and as the economy grinds slower and slower, we're already feeling the effects of that."
- "This is the biggest dive destination in the world. We have the most charter boats, the largest commercial fishing industry, the leading tourism economy, and none of these things are possible when you have an energy crisis and when you have more and more devastating hurricanes and storms, which also have severe consequences on the coral reef as well, but I think the energy crisis is going to have a stronger impact on our economy than anything else at this point."
- Solar energy has huge potential, and some people here are investing in a revolutionary approach to harness the power of the ocean. But we need a political mind-set and an agenda that is driven by looking at those alternatives as opposed to the current oil regime.
- The compressed air car (New Zealand, Spain, France).
- New Honda hydrogen car.
- California is more innovative in adopting alternative fuels than other states.
- The utility companies had a suggestion for No Name Key to sell their excess power to the utility companies. However, it appears to have been politically motivated. Meanwhile, the example of people choosing to live with renewable energy on No Name Key will be increasingly important.
- "Conflict of alliances or development of the no carbon dioxide emissions, so let's use that to have nuclear energy coming along. And that scares me tremendously. I can see this alliance of interests taking us to that solution."
- Florida Power & Light is the largest producer of wind power and it's in Arizona. The Keys don't have the constant wind required.
- What we do have here is constant tides and waves, and that's what we're trying.
- "Nuclear energy has been brought up here. I just hope that that is not part of the future. It really, really scares me."

## KEY WEST

### *The economy*

- Popular perception is that fishing, not tourism, is our economy.

- We are a tourism economy, everything else is somehow tied to that.
- Part of the problem is that we are a transient community. High turnover of inhabitants.
- Tourism is a big component of our overall economy, but real estate is the catalyst that makes it work.
- Real estate bubble has now burst, with a lot of people caught up.
- We have gone from a part-time to a full-time economy in 25 years, and now we are probably readjusting again.
- Real estate will always be expensive in the Keys. Always was.
- US economy has always been based on cheap fuel prices. Higher fuel prices inflationary because everything is tied to fuel.
- What drives conservation is the high cost of something. And the spillover effect is loss of revenues that circulate within the community.
- We conserve in the Keys because everything is so dear. We learned to live with smaller housing, etc.

***Key West differences***

- Added attractions: historical buildings and culture
- Cruise ships: businesses downtown want them but is the short-term gain for those businesses worth the long-term effect on the environment?
- We're 120 miles long and we're made up with individual communities who don't think beyond the boundaries of their individual community. One thing everyone else out of Key West has in common is they tend to dislike Key West.
- More people come here once and then stay in the Upper Keys and come down and visit than the other way around. There are more divers that dive throughout the Keys and on their last day they'll come down here to play and party.

***Tourism***

- Drives the economy.
- Tourism needs to be reduced to get higher scale people.
- Alternative of putting boat in water in Miami-Dade County taking an hour and a half, and driving to the Keys in three hours and have plenty of space.
- We need to protect all those things that produce money, and we need a better grade of tourist, but we also need all those folks in the middle.
- As we make the transition to this so-called upscale economy, we haven't upscaled our service and facilities.

***Better energy use, alternative energy sources***

- Is clean coal among them (proposal to SAC for a clean coal burning furnace)?

- Need for big push to build cisterns for houses, and solar energy to run everything except the central AC. Would make us more stable from an energy standpoint.
- Peak oil – if here, prices will stay high and rise. Most dramatic short-term impact on Keys economy.
- Save fuel with more energy-efficient cars that can only do 80 miles an hour.
- Biodiesel from corn. Allegedly not a cause of increase in food prices, which are going up because of India and China. The new ethanol plants are more efficient.
- Windmills. North Dakota could generate enough electricity for the entire country. But there is the transit issue.
- Windmills not suitable for Keys.
- New solar technologies, plus longer-lived units being developed.
- Tidal power.
- Very little solar power installed in Keys: five houses tied to the grid, and some communities have no electricity except solar panel.

## EDUCATION AND OUTREACH

### KEY LARGO

***Education, communication and enforcement***

- It comes down to these three things.
- Lack of law enforcement and education: Boats can be rented showing a credit card and driver's license. Some hoteliers try to educate people by suggesting alternatives and informing about the seagrass and the reef. Law enforcement allegedly in decline and people blatantly break laws, e.g. fishing in no-catch zones.

### ISLAMORADA

***Central role of education***

- Central to everything
- Need to educate locals – especially those who have lived here a long time – on sustainable behavior, e.g., mitigation for stormwater runoff in the interest of community character.
- Need to educate visiting as well as local boaters to limit damage to reef.
- Encourage environmentally aware major tourist attractions (like Walt Disney World), and also chambers of commerce etc, to educate visitors. They can act as a stimulus for other proactive companies on both small and larger scale. "Not only is it the right thing to do, but it also makes business sense."

- Using climate change will overwhelm people, be more subtle. For example, people may ask if operators are doing something in the Green Lodging Program (which makes each guest feel part of the solution). Basically, give people an idea of how they can help. Green Lodging Program
- Problems educating diverse ethnic populations with different cultures, especially older generations. Since some of them are poor, this represents an important part of their food sources. You can iron-fist it, or you can through education, which is going to be a long, tough, hard row to hoe. Often you're not going to be able to touch the parents and the grandparents, but you can break the chain through the children and the schools.
- "Kids have an actual physical relationship to a lot of these things, they've seen the manatees, hang out on coral reefs, I think it's easy for education here." One response to this was: "I don't know. I have to teach them what happens when you flush a toilet when they came in and helped develop our web site. It's amazing when they understood what happens when you flush a toilet around here."
- Overcoming individual rights v collective good
- Role of education in changing ingrained habits (such as littering)

## MARATHON

### *Tourism and education*

- Key to future is switching gears to education-based tourism: ecotourism
- Having educational institutions invest in ecotourism education center; ecotourists would be much better stewards of the environment
- The opportunities in regards to bolstering our education, a college presence in the Keys and focusing on that and ecotourism could not completely replace recreational fishermen and recreational scuba diving, but it could be something that the community seriously needs to look at.
- People in the dive industry, in various NOAA facilities, a lot of people down here with Ph.D.s with time on their hands. If we create a community environment that welcomes that, we could change the dynamics of the community.
- Selling the idea of more no-take areas through education and outreach to the general public, both commercial and recreational fishermen. But difficult to understand why clear data showing over-fishing (especially targeting some specific fish) doesn't make people want to protect those resources as best they can.

## LOWER KEYS

### *Education and outreach*

- Referring to the point about getting on the bandwagon (GLEE etc), it's education, it's outreach, it's keeping the course, working with people and getting them to understand. We got through getting them to understand about damaging coral when first they didn't get it.  Now we're doing that with seagrass and they're starting to get it with seagrass. It may take a while but we are getting there.

- Concentrating on the young while it is hard to change the attitudes of adults. Getting the students to teach their parents.
- “Our high school in Key West is very proactive in reference to looking for alternatives. They're light years ahead of us.”
- “We have so many in the Keys that's already leading by example, whether it's the homes out on No Name Key that, when GLEE does tours out there, people line up to see the fact that they don't live much differently than anybody else.  That's what I love about it.”
- Spending a little bit more and then seeing real savings: “The ultimate grass roots level is that by upping their recycling from 6 percent to 7.6 percent the residents of Key West saved the city $8,000 in three months.

***Sanctuary management***

- We are not managing the resources, we are managing people's activity and how they affect those resources. But GBRMPA [Australia] developed a reef managers’ guide which is a response to coral bleaching. It points out that awareness and communication is the first step, and as a result we can now talk openly about “climate change” and “sequences”.
- The first thing to start getting people to recognize it is to know the reefs are going to change – we don’t know how but we know they will. Sea levels will also change, but we don’t know how much or how fast, but just knowing that we can start preparing ourselves economically and socially and environmentally for those changes as they take place and start thinking in terms of building resilient coastal communities, as well as having resilient marine and coastal resources.

## KEY WEST

***Education***

- Educate individual people on the environment.
- Green lodging: Everybody involved in the program is happy with the Keys because the educational thing is huge. And it puts a focus on the environment.
- “Most of us tend toward environmentalism, yet our economy is almost completely dependent on the excess or the extravagant use of energy to bring tourists to us. We don't want to stop the tourism, because that's the life blood of the economy, but if 3 to 4 million people come down here, that's a great opportunity to educate a large number of people that reduces our so-called footprint.”
- 20% biodiesel in boats, solar panels on your building, tie it in with the global change and the impact it could have on the reef.
- Hotels have an opportunity to educate lots of people, and not just green lodge.
- Two key issues: education and regulations.

- We need to educate people on the success of things.
- "Unless it moves up to Miami-Dade County or it moves to another state, we're still going to be impacted, and, how do we tie that political will in that needs to happen?" That's why GLEE was started, which should become part of a larger organization.

***Past mistakes***

- Weren't even monitoring carbon dioxide 50 years ago.
- Corps of Engineers wanting to reroute the Everglades.
- Insufficient zoning requirements.
- Some business decisions which became political decisions have problems now from the standpoint of the real estate market collapsing. But Keys will recover because we have only a limited amount of real estate.
- "We're going through a natural expansion/contraction of our economy. I think the unfortunate part is we've never learned past history lessons as to what's going on."
- "We look at everything in the short-term year-to-year budget, administration to administration, without a long-term planning sequence that private enterprise can go into."

***Marketing the change***

- Conservation and the green movement have gotten some traction over the last few years.
- Green lodging: If we can get half the people to support it, they find that actual savings are realized and conclude that it's good for business.
- Teaching people to use energy sensibly, including transportation (limit car use to go shopping from frequent small to major planned trips).
- Billboards on the Keys: "You are now entering a national marine sanctuary, tread softly", and "observe, preserve, conserve" which is the message we need to give out.
- "We need to take a portion of those funds that we collect to protect or control and put it into marketing. I know that sounds a little bit like Big Brother, but we have to say it and make it cool. And when you have people like Crist or Obama or Tiger Woods stand up and say, you know, "The coral reefs are the greatest things and we have to protect it," that's marketing. That's just getting that icon out there that's telling the message."
- We have to take the scientific information (which can bore people) and put it into precise promotional concepts for people.
- "Shifting baselines: We all realize the changes, but everyday people come in and they go, "My God, it was so beautiful out there," and we're thinking you should have seen it years ago. In future, is it going to be more degraded? Are the people seeing it for the first time still going to be enthused about it? You know, it's a scary thought. We're never going to get our fisheries back to what they were in the past, but how do we make them sustainable and get that message out to the people?"

- “It's mandatory that we put some planning into sustaining what makes us us. You come down the Keys and you're driving and you hated Miami, then all of the sudden something happens, your whole feeling changes.”
- A strong majority of the people don't want to see a whole lot more development in the Keys. They want to protect the community character that they see here and they think it's the tipping point to where if some of the things that continue to go on, and the only thing that saved us to a great degree gives us another bite at the apple is the economy, because a lot of these projects would be going on still today if the housing market hadn’t declined.

# APPENDIX 3: CHANGING GLOBAL SCENARIOS

## INTRODUCTION AND SUMMARY

The outlook for global climate change has deteriorated, and the scientific understanding of the associated dynamics and risks has improved, since the IPCC scenarios which remain in force were prepared in the late 1990s and published in the *Special Report on Emissions Scenarios* (Nakicenovic et al. 2000). This was documented in the Fourth Assessment Report (Pachauri and Reisinger 2007), but the outlook has continued to worsen since then.

Plans are underway to develop scenarios – both on emissions and the underlying narratives – in time for the fifth assessment in 2014. Meanwhile, however, we are stuck with decade-old scenarios, and the crucial question is how (a) the storylines, (b) the emissions scenarios and (c) the economic and social implications can be developed to remain internally consistent. This has been a major hurdle in the preparation of this report, which was not fully anticipated when the scoping report was written (Hoegh-Guldberg 2005).

It was a main challenge for the Florida Keys project. We needed to develop a set of four plausible scenarios from an updated set of IPCC scenarios, starting globally and then pursuing the course via the United States towards ultimate scenarios for the Keys (where we have the added benefits of insights through the five scenario-planning workshops conducted in June 2008, and further feedback through meetings in August 2009). These scenario stories could then be supplemented with quantitative estimates of key physical and economic variables, along the lines of the Great Barrier Reef report which provided the initial model for the Keys study (Hoegh-Guldberg and Hoegh-Guldberg 2004).

In the effort to update the scenario basis, we selected a number of recent global scenarios and descriptions which imply certain scenarios. They all indicate that the need for action has become more urgent since 2000. The selection ranges from the ongoing work on the United Nations Millennium Development Goals and the comprehensive review of the science contained in Mark Lynas's *Six Degrees*, to contributions by economists and others which prescribe a way out of the problem over the 21$^{st}$ century and describe the dire effects of "business-as-usual" or "BAU" scenarios.

The final selection is based on one prominent scientist's continued efforts to warn the world. James Hansen of NASA's Goddard Institute for Space Studies has maintained a high profile as a climatologist since the 1970s. He continues to provide compelling evidence, based on a combination of contemporary and paleoclimate data, that the need to correct for climate change has become significantly more urgent – the tipping point is here, or near. During 2009, many others joined Hansen's advocacy to keep the level of atmospheric $CO_2$ below 350 ppm to limit the rise in average temperatures to a "reasonably safe" 2$^{O}$C in the 21$^{st}$ century. The concluding sections of this appendix reflect this.

While this task has become generally more critical, there is a deepening understanding of the need to mitigate against increasing greenhouse gas emissions, both at national and international level, as well as in many local settings. There is hope, but no certainty, that international action will eventuate in time to avoid disaster. Crucial to this is international cooperation, and the full engagement of the United States in a leadership role. Unfortunately, the global economic crisis interfered with public and political perceptions during 2009 and climate change took a backseat while "climate denialism" became prominent.

An "endnote" to the main scenario analysis is based on a small empirical study of one popular science journal, *New Scientist.* It could be extended to other journals but is likely to be typical. The object was to measure, through the journal's internal search engine, whether there has been an increase in the number of items dealing with climate change over the past two decades, as an indication that climate change has become a more urgent problem, recognized by a widely read and respected popular science publication. It shows convincingly that there has been a strong increase in the number of climate change-related items in the last few years (with a leap in the second half of 2009, leading up to the Copenhagen COP-15 meeting in December), which provides some reassurance that comprehensive action will follow sometime in the not too distant future.

Finally, the link from global scenarios through the United States to the Florida Keys needs to be established. The main Florida Keys report refers to the state-of-knowledge report by the US Global Change Research Program (USGCRP) under the auspices of the Office of Science and Technology Policy and NOAA (Karl et al. 2009). As background for the US analysis, this document contains a powerful synthesis of global climate change prefaced by the evidence from Antarctic ice core data that the concentration of carbon dioxide never in 800,000 years exceeded 300 parts per million – until 1911. In 1959 when the present Mauna Loa data begin, the level was 316 ppm, from which it reached 387 ppm in 2009, 30% above the past maximum level in that has been measured in geological time.

The USGCRP graph shows a "lower-emissions scenario" reaching 550 ppm by 2100, and a "higher emissions scenario" reaching 900 ppm. Even the lower level is far too high, a view shared by the authors of the USGCRP report and the accumulated evidence in this appendix, which concludes that the atmospheric content of $CO_2$ must be reduced if global temperatures have any reasonable chance of staying within $2^{O}C$ above pre-industrial levels.

Another link from global to local concerns the scenario storyline. Chapter 7 in the main report ends with Keys-specific scenarios preceded by a brief outline of possible US-wide futures based on Cullen Murphy's *The New Rome?* (2007), including the "Titus Livius hundred-year workout plan," which would fit in with the global B1 scenario (adding a "green tinge"). Murphy also outlines three "all too plausible" American scenarios, summarized in the final addendum to this appendix.

# EVOLUTION OF IPCC SCENARIOS

## SCENARIOS FOR THE THIRD ASSESSMENT REPORT (TAR)

### *Background*

The IPCC first developed scenarios in 1990 for its First Assessment Report in 1990. In 1992, the report was updated for the Earth Summit Conference in Rio de Janeiro, and the reference scenarios for the 1990 report were substantially extended into six new climate change scenarios, named IS92a-f. The scenarios were evaluated in 1995 in connection with the Second Assessment Report, finding that significant changes since 1992 in the understanding of driving forces of emissions and methodologies should be addressed.

This led to a recommendation by the IPCC Plenary in 1996 to create a new set of scenarios, which were then developed over the next four years resulting in the *Special Report on Emissions Scenarios* (Nakicenovic et al. 2000).

The report adhered to rules that were consistently followed in the Florida Keys project. They are stated briefly from the Third Assessment synthesis report (IPCC 2001):

- Future greenhouse gas emissions are the product of complex dynamic systems, determined by driving forces including demographic and socioeconomic development, and technological change.
- A set of scenarios was developed to represent the range of driving forces and emissions in the scenario literature based on current understanding and knowledge about underlying uncertainties. The only exclusions are outlying "surprise" or "disaster" scenarios in the literature.
- There is no preference for any of the scenarios, they are not assigned probabilities of occurrence, and they should not be interpreted as policy recommendations. Their role is to outline the boundaries of what is plausible and capable of adjustment through policy, not to provide predictions.
- Four different narrative storylines were developed to describe consistently the relationships between emission-driving forces and their evolution and to add context for the scenario quantification. Each storyline represents different social, economic, demographic, cultural, technological, political, and environmental developments.
- The scenarios cover a wide range of the main demographic, economic, and technological driving forces of greenhouse gases and sulfur emissions and are representative of the literature. Each scenario represents a specific quantitative interpretation of one of four storylines.
- No IPCC scenario explicitly assumes implementation of emissions targets set through the Kyoto Protocol or anything based on it. But greenhouse gas emissions are affected by non-climate change policies designed for a wide range of other purposes, and government policies influence emission drivers such as demographic change, social and economic development, technological change, resource use, and pollution management. This is broadly reflected in the storylines and resultant scenarios.
- For each storyline several different emissions scenarios were developed (constituting a scenario "family") using different modeling approaches to examine the range of outcomes arising from a variety of models that use similar assumptions about driving forces. This resulted in 40 scenarios that together encompass the current range of uncertainties of future greenhouse gas emissions arising from different characteristics of these models. From these, six different 'marker scenarios' were selected.

## THE SCENARIOS

The storylines represented four possible global futures, basically defined along two axes: "economic" versus "environmental" (the 'A' and 'B' dimension), and "global" versus "regional" (the '1' and '2' dimension). The storylines are summarized as follows: [1]

- The A1 storyline and scenario family describe a future world of rapid economic growth, with a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. Three variants of A1 describe alternative directions of technological change in the energy system: fossil intensive (A1FI), moving to a non-fossil energy base (A1T), and balance across all sources (A1B).

  A1B is IPCC's "marker" A1 scenario, but A1FI is often used by scientists and others as a worst-case "business-as-usual" scenario despite advice from IPCC that this goes against the philosophy of scenario planning as outlined on the previous page.

- The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

- The B1 storyline and scenario family describe a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

- The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population but at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

[1] The original storylines are shown in full in Chapter 7, and then significantly adapted. They were used, with some elaboration at the global level, in the report for WWF Australia on the implications of climate change for Australia's Great Barrier Reef (Hoegh-Guldberg and Hoegh-Guldberg 2004). The current study of the Florida Keys has developed and elaborated this approach further, taking into account changes in the long-term outlook over the first decade of the 21st century. Following the analysis of the increasing threat of climate change in the current appendix, Appendix 4 for the first time quantifies the possible collapse in the global economic product under conditions of severe climate change, Appendix 5 describes the "new" economics that may influence macroeconomic and financial policy including the impact of climate change itself, and Appendix 6 discusses limits to the types of new technology that may plausibly emerge.

***Main drivers of emissions***

The list below is edited from the summary for policymakers in the *Special Report on Emissions Scenarios* (Nakicenovic et al. 2000).

- The main driving forces of future greenhouse gas trajectories will continue to be demographic change, social and economic development, and the rate and direction of technological change.
- All scenarios describe futures that are generally more affluent than today. The scenarios span a wide range of future levels of economic activity, with gross world product rising to 10 times today's values by 2100 in the lowest to 26-fold in the highest scenarios.[2]
- A narrowing of income differences among world regions is assumed in several SRES scenarios. Two of the scenario families, A1 and B1, explicitly explore alternative pathways that gradually close existing income gaps in relative terms.
- Technology (see Appendix 6) is at least as important a driving force as demographic change and economic development. The three driving forces are interrelated.
- In most scenarios, the global forest area continues to decrease for some decades, primarily because of increasing population and income growth. This trend is eventually reversed with the greatest increase in forest area by 2100 in the B1 and B2 scenario families, as compared to 1990.
- All the above driving forces not only influence $CO_2$ emissions, but also the emissions of other greenhouse gases. The relationships between the driving forces and non-$CO_2$ emissions are generally more complex and less studied (though much progress is being made), and the models used for the scenarios less sophisticated. Hence, the uncertainties in the SRES emissions for non-$CO_2$ greenhouse gases are generally greater than those for energy $CO_2$.

***Robust findings and key uncertainties***

The final *Summary for Policymakers* (IPCC 2001) posed and answered nine questions. The last one responded to issues raised in previous chapters by defining *robust findings* (which hold under a variety of approaches, methods, models and assumptions and are expected to be relatively unaffected by uncertainties) and *key uncertainties* (which may lead to new and robust findings in relation to the nine questions). They are detailed in Table SPM 3 of the IPCC *Summary*, and are reflected in the following list of key concerns.

***Five reasons for concern***

Working Group 2 of the IPCC Third Assessment (Smith, Schellnhuber and Mirza 2001) identified five main reasons for concern, which is highly relevant because the reasons were assessed again in the Fourth Assessment, discussed below. The reasons for concern are:

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[2] This assumption is taken up in Appendix 4, which contests the assumption that economic growth will continue unabated in worlds affected by much higher temperatures and other effects of advanced climate change. This also affects the interpretation of the next point, which states that the two "global" scenarios A1 and B1 explicitly explore alternative pathways that gradually close existing income gaps. This would only be practically possible when economic growth is well maintained.

1. Unique and threatened systems including tropical glaciers, coral reefs, mangroves, biodiversity hotspots, and ecotones (transition areas between two adjacent ecosystems). There are numerous examples of unique and threatened entities that are confined to narrow geographical ranges and are very sensitive to climate change. However, their degradation or loss could affect regions outside their range. There is medium confidence that many of these unique and threatened systems will be affected by a small temperature increase. For example, coral reefs will bleach and glaciers will recede; at higher magnitudes of temperature increase, other and more numerous unique and threatened systems would become adversely affected.
2. *Distributional impacts*: The impact of climate change will not be evenly distributed among the peoples of the world. There is *high confidence* that developing countries tend to be more vulnerable to climate change than developed countries, and *medium confidence* that climate change would exacerbate income inequalities between and within countries. There is also *medium confidence* that a small temperature increase would have net negative impacts on market sectors in many developing countries and net positive impacts on market sectors in many developed countries. However, there is *high confidence* that with medium to high increases in temperature, net positive impacts would start to decline and eventually turn negative, and negative impacts would be exacerbated.
3. *Aggregate impacts*: The authors address how aggregate impacts change as global mean temperature increases, whether aggregate impacts are positive at some levels of temperature increase and negative at others, whether change will occur smoothly or in a more complex dynamic pattern, and whether aggregate impacts mask unequal distribution of impacts. Some studies find a potential for small net positive market impacts under a small to medium temperature increase. However, given the uncertainties about aggregate estimates, the possibility of negative effects cannot be excluded. In addition, most people in the world would be negatively affected by a small to medium temperature increase. Most studies of aggregate impacts find that there are net damages at the global scale beyond a medium temperature increase and that damages increase from there with further temperature increases. By its nature, aggregate analysis masks potentially serious equity differences.
4. *Extreme weather events*: As the global mean climate changes, so too will the probability of extreme weather events such as days with very high or very low temperatures, extreme floods, droughts, soil moisture deficits, tropical cyclones and other storms, and fires. The frequency and magnitude of many extreme climate events increase even with a small temperature increase and will become greater at higher temperatures (*high confidence*). The impacts of extreme events are often large locally and could strongly affect specific sectors and regions. Increases in extreme events can cause critical design or natural thresholds to be exceeded, beyond which the magnitude of impacts increases rapidly (*high confidence*).
5. *Large-scale singularities* in the response of the climate system to external forcing, such as shutdown of the North Atlantic thermohaline circulation or collapse of the West Antarctic Ice Shelf, have occurred in the past as a result of complex forcings. Similar

events in the future could have substantial impacts on natural and socioeconomic systems, but the implications have not been well studied. Determining the timing and probability of occurrence of large-scale singularities is difficult because these events are triggered by complex interactions between components of the climate system. The actual impact could lag behind the climate change cause (involving the magnitude and the rate of climate change) by decades to millennia. There is *low to medium confidence* that rapid and large temperature increases would exceed thresholds that would lead to large-scale singularities in the climate system.

## THE FOURTH ASSESSMENT REPORT (AR4), 2007

The IPCC's main assessment of climate change in the Fourth Assessment is in the synthesis report (Pachauri and Reisinger 2007). The focus here is on the comparison with the Third Assessment in the effort to ascertain changes in the severity of climate change. AR4 again contains a list of robust findings and key uncertainties for reference, while the key reasons for concern were updated as follows.

### *The five reasons for concern updated*

The five 'reasons for concern' identified in the TAR were intended to "aid readers in making their own determination" about risk. They are now regarded as more serious with many risks identified with higher confidence. Some are projected to be larger or to occur at lower increases in temperature. This is due to (1) better understanding of the magnitude of impacts and risks associated with increases in global average temperature and greenhouse gas concentrations, including vulnerability to present-day climate variability, (2) more precise identification of the circumstances that make systems, sectors, groups and regions especially vulnerable, and (3) growing evidence that the risk of very large impacts at multiple-century time scales would continue to increase as long as greenhouse gas concentrations and temperature do so. The five 'reasons for concern' remain a viable framework for considering key vulnerabilities:

1. There is new and stronger evidence of observed impacts of climate change on *unique and vulnerable systems* such as polar and high mountain communities and ecosystems, with the adverse impacts increasing as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with *higher confidence* than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5-2.5$^0$C over 1980-1999 levels. *Confidence has increased* that a 1-2$^0$C increase in global mean temperature above 1990 levels poses significant risks to threatened unique systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1-3$^0$C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatization by corals. Increasing vulnerability of Arctic indigenous communities and small island communities to warming is projected.
2. *Risks of extreme weather events*. Responses to some recent extreme climate events reveal higher levels of vulnerability in both developing and developed countries than

was assessed in the TAR. There is now *higher confidence* in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. Increases in drought, heat waves and floods are projected in many regions and would have mostly adverse impacts, including increased water stress and wildfire frequency, adverse effects on food production, adverse health effects, increased flood risk and extreme high sea level, and damage to infrastructure.

3. *Distribution of impacts and vulnerabilities*. There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change and are frequently the most susceptible to climate-related damages, especially when they face multiple stresses. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing countries but everywhere. There is greater confidence in the projected regional patterns of climate change and in the projections of regional impacts, enabling better identification of particularly vulnerable systems, sectors and regions. Moreover, there is increased evidence that low-latitude and less developed areas generally face greater risk, for example in dry areas and mega-deltas. New studies confirm that Africa is the most vulnerable continent because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea-level rise are projected particularly for Asian mega-deltas and for small island communities.

4. *Aggregate impacts*. Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude and therefore sooner than was assessed in the TAR. It is likely that there will be higher damages for larger magnitudes of global temperature increase than estimated in the TAR, and the net costs of impacts of increased warming are projected to increase over time. Other aggregate impacts have also been quantified; for example, climate change over the next century is likely to adversely affect hundreds of millions of people through increased coastal flooding, reductions in water supplies, increased malnutrition and increased health risks.

5. *Risks of large-scale singularities*. During the current century, a large-scale abrupt change in the meridional overturning circulation (thermohaline circulation) is *very unlikely*. There is *high confidence* that global warming over many centuries would lead to a sea-level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20$^{th}$ century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea-level rise from both the Greenland and possibly the Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century timescales. This is because recently observed dynamic processes involving ice which are not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. The complete disappearance of the Greenland ice sheet would raise sea level by 7m and could be irreversible.

***Updating the emissions scenarios***

*There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global greenhouse gas emissions will* *continue to grow over the next few decades. Baseline emissions scenarios published since the* Special Report on Emissions Scenarios (*Nakicenovic et al. 2000*) *are comparable in range with those presented there.*

For the next two decades a warming of about 0.2$^0$C per decade is projected for a range of SRES emissions scenarios. Subsequent temperature projections increasingly depend on specific emissions scenarios.

Continued emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21$^{st}$ century that would *very likely* be larger than those observed during the 20$^{th}$ century.

Advances in climate change modeling now enable best estimates and likely assessed uncertainty ranges to be given for projected warming for different emissions scenarios.

Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8$^O$C), they are not directly comparable. Assessed upper ranges for temperature projections are larger than in the TAR mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. For the A2 scenario, for example, the climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1$^0$C.

Model-based projections of global average sea-level rise at the end of the 21$^{st}$ century (2090-2099) for each scenario are within 10% of the TAR model average for 2090-2099. The sea-level projections do not include uncertainties in climate-carbon cycle feedbacks nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. Therefore the upper values of the ranges given are not to be considered upper bounds for sea-level rise. The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. If this contribution were to grow linearly with global average temperature change, the upper ranges of sea-level rise for SRES scenarios would increase by up to 0.2m.

*There is now higher confidence than in the TAR in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and sea-ice .*

Projected warming in the 21$^{st}$ century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and northern North Atlantic, continuing recent observed trends.

Snow cover area is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Sea-ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea-ice disappears almost entirely by the latter part of the 21$^{st}$ century.

It is *very likely* that hot extremes, heat waves and heavy precipitation events will become more frequent.

Based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period.

Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns, continuing the broad pattern of observed trends over the last half century.

Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100), continuing observed patterns in recent trends.

## TOWARDS NEW IPCC SCENARIOS

### *Background*

The IPCC scenario process is lengthy and time-consuming: it took four years to complete for the Third Assessment in 2001. Because of the time factor there were no new scenarios for the Fourth Assessment Report in 2007, although some 'post-SRES' scenarios were developed within the general context, and the framework used to measure future changes.

New scenarios for the process were discussed during several IPCC sessions and in a series of workshops starting in Washington, DC, in January 2005. In April 2006, the IPCC decided that rather than continuing to coordinate the process of developing scenarios for its assessment itself, the process should in future be coordinated by the research community. The IPCC would seek to "catalyze" the timely production by others of new scenarios for a Fifth Assessment Report by convening an expert meeting to consider the scientific community's plans for developing new scenarios, and to identify a set of "benchmark emissions scenarios" (subsequently renamed "representative concentration pathways").

The expert meeting took place in the Netherlands in September 2007. It was attended by over 130 scenario users including representatives of national governments, international organizations, multilateral lending institutions, and NGOs. The main research areas represented at the meeting were integrated assessment modeling (IAM), climate modeling (CM), and the impacts, adaptation and vulnerability (IAV) community. Over 30% of the participants represented developing countries. With this broad participation, the meeting provided an opportunity for all segments of the research community involved in scenario development and application to discuss their respective requirements and coordinate the planning process. The meeting resulted in a comprehensive report (Moss et al. 2008).

While the development of actual scenarios will be far too late for the Florida Keys project to benefit, the new recommended concepts are noted and taken into account to the extent possible.

### *Near-term and long-term scenarios*

Based on the interests and needs of end users, the new scenario process will develop global scenarios for two time periods:

- "near-term" scenarios that cover the period to about 2035; and
- "long-term" scenarios that cover the period to 2100 and beyond.

Key issues for the *near-term* scenarios include identifying immediate risks, developing corresponding adaptive capacity, reducing vulnerability, making efficient investments to cope with climate change, and implementing investments in low-emission technologies, energy conservation, and sink preservation and/or enhancement. This is a new activity for climate modelers and, as such, is a research issue in progress.

The *long-term* policy focus shifts towards evaluating climate targets to avoid risks from climate change impacts, improving the understanding of risks of major geophysical and biogeochemical change and feedback effects, and adopting strategies for adaptation, mitigation, and development that are robust over the long term to remaining uncertainties. Alternative climate scenarios provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems.

At the expert meeting, representatives of the policy community expressed a strong interest in very low radiative forcing profiles, down to radiative forcing that peaks ('overshoots') at three watts per square meter ($3W/m^2$) before 2100 and then declines.[3] The policy discussion is moving towards increasingly stringent emission reduction targets, and policymakers will need information on the implications of these climate change targets, unavoidable impacts of even low trajectories, and economic and technological pathways for achieving these targets. In fact, a discussion note commenting on the report (Meinshausen and Hare 2007) finds a strong case for an emissions scenario that stabilizes significantly below $3W/m^2$. [4]

### *Representative concentration pathways*

The name "representative concentration pathways" (RCPs) reflects their rationale. As *pathways*, their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas concentrations. The term pathway is also meant to emphasize that the trajectory that is taken over time is of interest as well as the specific long-term *concentration* or radiative-forcing outcome, such as a stabilization level. They are *representative* because they are one of several different scenarios that have similar radiative-forcing and emissions

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[3] Radiative forcing is used to assess and compare the anthropogenic and natural drivers of climate change. The measures in watts per square meter can be related through a linear relationship to the global mean equilibrium surface temperature change (Forster, Ramaswami et al. 2007, p 133).

[4] "Achieving the EU $2^{O}C$ target with at least a *likely* chance would require long-term stabilization below 400 ppm $CO_2$ equivalence or $2W/m^2$ (although an intermediate peaking level at maximally $3W/m^2$ might be consistent as well)." (Meinshausen and Hare 2007, p 98) These authors therefore proposed replacing the proposed low radiative forcing model which peaks near $3W/m^2$ and then declines to $2.9W/m^2$, with another that peaks at over $3W/m^2$ but then declines to $2.6W/m^2$. Further tests would determine which would be the final candidate (Moss et al. 2008, pp xvii and 39).

characteristics (Moss et al. 2008, pp iv-v). The parallel with the SRES scenario families is noted.

For a particular integrated assessment model (IAM) to be considered an RCP, it has to be peer-reviewed and published, apart from meeting other criteria (Moss et al. 2008, p 36). The type of RCP was of course a central consideration: the pathway must correspond to one of the four RCP types that satisfy the desirable characteristics:

1. RCP 8.5 (>8.5W/$m^2$ in 2100, rising. Carbon dioxide-equivalent ($CO_2e$) concentration in 2100: >1,370 ppm)
2. RCP 6 (about 6W/$m^2$ at stabilization after 2100, stabilization without overshoot. $CO_2e$ concentration in 2100: 850 ppm)
3. RCP 4.5 (about 4.5W/$m^2$ at stabilization after 2100, stabilization without overshoot. $CO_2e$ concentration at stabilization after 2100: 650 ppm)
4. RCP 3-PD (peak at about 3W/$m^2$ before 2100 and then decline. Peak in $CO_2e$ concentration before 2100: 490 ppm, then decline).

To put these estimates into perspective, Table SPM.5 in IPCC (2007, p 67) relates six categories of radiative forcing to measures of $CO_2$, temperature and other variables (it may be noted that these are all above the assessment by Meinshausen and Hare quoted below, let alone more recent assessments by James Hansen and others described toward the end of this appendix):

- Category I: radiative forcing is 2.5-3.0 W/$m^2$. $CO_2$ concentration stabilizes at 350-400 ppm ($CO_2e$ at 445-490 ppm). Climate sensitivity: +2.0-2.4$^0$C. Peak year for $CO_2$ emissions by 2015. $CO_2$ emissions in 2050 relative to 2000: -85% to -50%.
- Category II: radiative forcing 3.0-3.5 W/$m^2$. $CO_2$ stabilizes at 400-440 ppm, $CO_2e$ at 490-535 ppm. Climate sensitivity: +2.4-2.8$^0$C. Peak emissions by 2020. Emissions 2050: -60% to -30%.
- Category III: radiative forcing 3.5-4.0 W/$m^2$. $CO_2$ stabilizes at 440-485 ppm, $CO_2e$ at 535-590 ppm. Climate sensitivity: +2.8-3.2$^0$C. Peak emissions by 2030. Emissions 2050: -30% to +5%.
- Category IV (118 of the 177 total scenarios assessed in all categories): radiative forcing 4.0-5.0 W/$m^2$. $CO_2$ stabilizes at 485-570 ppm, $CO_2e$ at 590-710 ppm. Climate sensitivity: +3.2-4.0$^0$C. Peak emissions by 2060. Emissions 2050: +10% to +60%.
- Category V: radiative forcing 5.0-6.0 W/$m^2$. $CO_2$ stabilizes at -570-660 ppm, $CO_2e$ at 710-855 ppm. Climate sensitivity: +4.0-4.9$^0$C. Peak emissions by 2080. Emissions 2050: +25% to +85%.
- Category VI: radiative forcing 6.0-7.5 W/$m^2$. $CO_2$ stabilizes at 660-790 ppm, $CO_2e$ at 855-1,130 ppm. Climate sensitivity: +4.9-6.1$^0$C. Peak emissions by 2090. Emissions 2050: +90% to +140%.
- Most scenarios stabilize sometime between 2100 and 2150.

The identification of RCPs is only the first step in an elaborate process being progressively developed between 2009 and 2012:

- *The four RCPs* would include time paths for emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use and land cover.
- *Ensembles of time-dependent projections of climate change* produced by multiple climate models including atmosphere-ocean general circulation models, earth system models and regional climate models will be prepared for the four long-term RCPs, and high-resolution, near-term projections to 2035 for the 4.5 $W/m^2$ stabilization RCP only. These projections can be scaled upward or downward according to the ratio of simulated global mean temperature for the RCP and the temperature change defined in simple climate models forced with different scenarios.
- *New IAM (Integrated Assessment Model) scenarios* will be developed exploring a wide range of dimensions associated with anthropogenic climate forcing. Anticipated outputs include alternative socioeconomic driving forces, alternative technology development regimes, alternative realizations of earth system science research, alternative stabilization scenarios including traditional "not exceeding" scenarios, "overshoot" scenarios, and representations of regionally heterogeneous mitigation policies and measures, as well as local and regional socioeconomic trends and policies.
- *Global and large-region narrative storylines* are detailed descriptions associated with the four RCPs, which will be developed by researchers from the IAM community and the IAV (Impacts, Assessment and Vulnerability) community.
- *Integrated scenarios*. RCP-based climate model ensembles and pattern scaling will be associated with combinations of new IAM scenario pathways to create combinations of ensembles. These scenarios will be available for use in new IAV assessments. In addition, IAM research will begin to incorporate IAV results, models, and feedbacks to produce comprehensively synthesized reference, climate change, and IAM results.

All this goes beyond the time horizon of the Florida Keys study. While the storylines for this project are derived from the scenarios first published in 2000, updated to take account of changes over the past decade, IPCC's planned scenario work as outlined in Moss et al. (2008) is kept in mind.

The key consideration remains how to assess the changes that have occurred in the severity of climate change compared with the SRES scenarios. The Fourth Assessment Report gives us some clues but not the full story. We have to look further.

### VARIABLE SOLAR ACTIVITY DOES NOT EXPLAIN CURRENT CLIMATE CHANGE

One of the arguments of climate change deniers (and even some who appear to be genuine skeptics) [5] is that changes in solar activity have caused a large proportion of the changes in

[5] It is important to distinguish between deniers and skeptics, as this report attempts to do throughout. "Denial of the science of climate change is eroding public understanding of the issue and seems to be undermining trust in scientists." (Kemp et al. 2010) The second observation reflects the debate, in late 2009/early 2010, on so-called

temperature that have been observed over the past century, citing variations in sunspot activity affecting solar luminosity. IPCC's Fourth Assessment Report shows that climate models using only natural forcings (from solar and volcanic activity) would likely have led to a slight cooling over the 20th century, but adding anthropogenic forces causes the increased temperature observed since about 1970 (Pachauri and Reisinger 2007, p 6).

Lockwood and Fröhlich (2007) come to a similar conclusion. While paleoclimate studies suggest that solar variability had an influence on the climate in pre-industrial (and geological) times, the impact since 1985 has been toward cooling.[6] "Our results show that the observed rapid rise in global mean temperatures seen after 1985 cannot be ascribed to solar variability, whichever of the mechanisms is invoked and no matter how much the solar variation is amplified." (p 2457)

Scientists at the Potsdam Institute for Climate Impact Research in Germany, Georg Feulner and Stefan Rahmstorf (2010), have taken the important extra step of simulating the most dramatic of the temperature cooling periods in the past millennium to assess its effect on the 21st century climate prospects. "The current exceptionally long minimum of solar activity has led to the suggestion that the Sun might experience a new grand minimum in the next decades, a prolonged period of low activity similar to the Maunder minimum in the late 17th century [from about 1645 to 1715]. The Maunder minimum is connected to the Little Ice Age, a time of markedly lower temperatures, in particular in the Northern hemisphere." (p 1)

Their conclusion is (p 5): "In summary, global mean temperatures in the year 2100 would most likely be diminished by about 0.1$^{O}$C. Even taking into account all uncertainties in the

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"scandals" following genuine mistakes by the IPCC (including that Himalaya's glaciers might disappear by 2035) and a much-publicized hacking of scientists' emails at the British East Anglia University Climate Research Unit (the CRU scientists were subsequently cleared of malpractice in July 2010 by the House of Commons Science and Technology Select Committee, though it found room for improvements in some of the CRU's working practices).

Denial is based on conviction or vested interest, rather than evidence. Denialists "use strategies that invoke conspiracies, quote fake experts, denigrate genuine experts, deploy evidence selectively and create impossible expectations of what research can deliver. They rely on misrepresentation and flawed logic." "By contrast, skepticism starts with an open mind, weighs evidence objectively and demands convincing evidence before accepting any claim. It contributes to the debate and forms the intellectual cornerstone of scientific enquiry."

Diethelm and McKee (2009) deal with "denialism" in the broad sense. They begin: "HIV does not cause AIDS. The world was created in 4004 BCE. Smoking does not cause cancer. And if climate change is happening, it is nothing to do with man-made $CO_2$ emissions. Few, if any, of the readers of this journal will believe any of these statements. Yet each can be found easily in the mass media." The paper is worth reading to the end. It quotes a definition of denialism (by Chris and Mark Hoofnagle) as "the employment of rhetorical arguments to give the appearance of legitimate debate where there is none." Kemp's and his co-authors' listing of denialist strategies comes from Diethelm's and McKee's paper.

[6] Lockwood and Fröhlich also refute an intriguing theory that changes in the intensity of cosmic-ray accelerators of supernova remnants in the Milky Way alter the Earth's cloudiness in the lower troposphere, with implications for climate change given that clouds have a cooling effect. Cosmic-ray counts vary with the strength of the solar magnetic field, which repels much of their influx from the galaxy (Svensmark 2007). "This mechanism .. has been highly controversial and the data series have generally been too short (and of inadequate homogeneity) to detect solar cycle variations in cloud cover; however, recent observations of short-lived (lasting of the order of 1 day) transient events indicate there may indeed be an effect on clean, maritime air." (Lockwood and Fröhling 2007, p 2449). Svensmark, who directs the Center for Sun-Climate Research at the Danish Institute of Space Research, has disputed this critique and the debate continues on the influence of galactic cosmic rays on (a) global temperature and (b) cloud cover (Wikipedia, 'Henrik Svensmark', accessed April 1, 2010).

temperature reconstruction, the forcings, and the model physics, the overall uncertainty is estimated to be at most a factor of 3, so the offset should not be larger than 0.3$^{O}$C. Comparing this to the 3.7$^{O}$C and 4.5$^{O}$C temperature rise relative to 1961–1990 until the end of the century under the IPCC A1B and A2 emission scenarios, respectively, a new Maunder-type solar activity minimum cannot offset the global warming caused by human greenhouse gas emissions. Moreover, any offset of global warming due to a grand minimum of solar activity would be merely a temporary effect, since the distinct solar minima during the last millennium typically lasted for only several decades or a century at most."

## OTHER SCENARIOS AND RELATED WORK

### THE MILLENNIUM PROJECT

#### *The Millennium goals*

The eight Millennium Development Goals for 2015, set in 2000 when the United Nations General Assembly adopted the Millennium Declaration (United Nations 2000), form a blueprint agreed to by all UN member countries and 25 leading global and major regional development institutions. They have galvanized unprecedented efforts to meet the needs of the world's poorest and form part of an ongoing project which provides the greatest guidance to the analysis of how the world may have changed since the SRES scenarios in 2000. The eight goals are shown below (slightly more detailed for the last two):

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women (including equal access to all education)
4. Reduce child mortality by two-thirds by 2015, compared with 1990
5. Improve maternal health, reducing the maternal mortality ratio by three-quarters
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability (integrating the principles of sustainable development into country policies and programs; reversing the loss of environmental resources; securing access to drinking water; and reducing the number of people living in slums)
8. Develop a global partnership for development (transparent trading and financial systems; addressing the special needs of the least developed and landlocked developing countries, and small island nations; addressing the debt problems of developing countries; developing and implementing strategies for decent work for young people; providing access to affordable essential drugs in developing countries; and making available the benefits of new technologies, especially information and communications).

The millennium goals are being constantly monitored, which makes the project assessment enormously useful of where the world is heading in respect of its environmental, social and economic characteristics. For further detail see United Nations Millennium Project (2005), where the eight goals are listed together with eighteen associated targets (pp xviii-xix).

***Four scenarios***

The quotation following this paragraph is from the Millennium Ecosystem Assessment (MA) synthesis volume, *Ecosystems and human well-being* (2005), p. 15. Full detail on the scenarios can be found in Chapter 8 of Carpenter et al. (2005). That volume includes great amounts of other essential reading, such as Chapter 4 on drivers of change, and Chapter 13 on lessons learnt for scenario analysis. The four scenarios summarized below are also described on the compact disc forming part of the Millennium Project's *2008 State of the Future* report (Glenn et al. 2008, Appendix O, pp 640-643).

"The MA developed four scenarios to explore plausible futures for ecosystems and human well-being based on different assumptions about driving forces of change and their possible interactions:

**Global Orchestration** – This scenario depicts a globally connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems, but it takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education. Economic growth in this scenario is the highest of the four scenarios, while it is assumed to have the lowest population in 2050.

**Order from Strength** – This scenario represents a regionalized and fragmented world, concerned with security and protection, emphasizing primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems. Economic growth rates are the lowest of the scenarios (particularly low in developing countries) and decrease with time, while population growth is the highest.

**Adapting Mosaic** – In this scenario, regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems. Economic growth rates are fairly low initially but increase with time, and population in 2050 is nearly as high as in *Order from Strength*.

**TechnoGarden** – This scenario depicts a globally connected world relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems. Economic growth is relatively high and accelerates, while population in 2050 is in the midrange of the scenarios."

It is emphasized (again) that the scenarios are not predictions but were developed to explore the unpredictable features of change in drivers and ecosystem services. Furthermore, no scenario represents business-as-usual, although all begin from current conditions and trends. These points are similar to IPCC's, and the four scenario summaries bear some resemblance to the four IPCC scenario families.

In general, the quantitative models used for these scenarios have addressed incremental changes but failed to address thresholds, risk of extreme events, or impacts of large, extremely costly, or irreversible changes in ecosystem services. These phenomena were addressed qualitatively by considering the risks and impacts of large but unpredictable ecosystem changes in each scenario.

Three of the scenarios incorporate significant changes in policies aimed at addressing sustainable development challenges. In *Global Orchestration* trade barriers are eliminated, distorting subsidies are removed, and a major emphasis is placed on eliminating poverty and hunger. In *Adapting Mosaic*, most countries by 2010 greatly increase their spending on education (from an average of 3.5% of GDP in 2000), and institutional arrangements to promote transfer of skills and knowledge among regional groups proliferate. In *TechnoGarden* policies are put in place to remunerate individuals and companies that provide or maintain the provision of ecosystem services, resulting in significant advances in the development of environmental technologies to increase production of services, create substitutes, and reduce harmful trade-offs.

***State of the Future***

The executive summary of the *2008 State of the Future* report is available online.[7] The printed report (Glenn et al. 2008) is backed by a compact disc containing a staggering 6,300 pages of research, and also reviews the Millennium Project's 12 years of study and analysis. The CD has a large chapter on past scenarios including a global normative scenario to 2050 (written in 1999), explorative scenarios to 2025 (written in the nineties), and even a set of very long-term scenarios to the year 3000. The 743-page Appendix O of the CD is an comprehensive annotated bibliography of more than 700 scenarios, to which about 50 are added annually. The scenarios are classified under the headings of international economics and wealth; environmental change and diversity; technological capacity; demographics and human resources; governance and conflict; regions and nations; and integration or whole futures.

In scenario-planning terms, the Millennium Project rivals the work of the IPCC, the sheer quantity of detail exceeds it, and it is being constantly monitored and updated. The material with its analysis of how the world is progressing towards the millennium goals (and the implications beyond 2015) adds richly updated knowledge to the IPCC scenarios.

The executive summary sets the stage. A small selection of quotations follows (compare the last part of this section which comments on the serious impact of the global economic downturn for poor countries, based on the 2009 *State of the Future* report which became available after the main part of this report was written):

"The future continues to get better for most of the world, but a series of tipping points could drastically alter global prospects. Half the world is vulnerable to social instability and violence due to rising food and energy prices, failing states, falling water tables, climate change, decreasing water-food-energy supply per person, desertification, and increasing migrations due to political, environmental, and economic conditions." (p 1)

"However, advances in science, technology, education, economics, and management seem capable of making the world work far better than it does today. Consider the extraordinary

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[7] http://www.millennium-project.org/millennium/sof2008.html. The 2009 report was published after the 2008 report was analyzed for the current project. It is also available in summary and is briefly described in the concluding part of the current section on the Millennium Project. The new main message is the impact of the global economic crisis. For detail see http://www.millennium-project.org/millennium/sof2009.html.

waste of human talent through violence, neglect, poor education, corruption, and other forms of inhumanity." (p 1)

"After 12 years of the Millennium Project's global futures research, it is increasingly clear that the world has the resources to address our common challenges. Coherence and direction are lacking. Ours is the first generation with the means for many to know the world as a whole, identify global improvement systems, and seek to improve such systems." (p 2)

"The digital gap continues to close around the world. The Internet is evolving from a passive information repository (Web 1.0), to a user-generated and participatory system (Web 2.0), and eventually to a more intelligent partner with collective intelligence and just-in-time knowledge (Web 3.0), eventually connecting humanity with much of the built environment. About 1.4 billion people (21% of the world) are connected to the Internet, with 37.6% of them in Asia, 27.1% in Europe, and 17.5% in North America. The Internet and mobile phones are merging, increasing access to the world's knowledge." (p 3)

***Global challenges***

The *State of the future* reports identify 15 global challenges which provide a framework to assess the global and local prospects for humanity. "The challenges are interdependent: an improvement in one makes it easier to address others; deterioration in one makes it harder to address others. Arguing whether one is more important than another is like arguing that the human nervous system is more important than the respiratory system." (p 10)

The challenges are described in Chapter 1 (pp 11-41), to which we refer. Referring to the 2008 report, it is worth listing them together with the response for meeting them in italics ("*Challenge 'x' will be addressed seriously when …*"):

1. How can sustainable development be achieved for all while addressing global climate change? *When GDP increases while global greenhouse gas emissions decrease for five years in a row.*
2. How can everyone have sufficient clean water without conflict? *When the number of people without clean water and those suffering from water-borne diseases diminishes by half from their peaks and when the percentage of water used in agriculture drops for five years in a row.*
3. How can population growth and resources be brought into balance? *When the annual growth in world population drops to fewer than 30 million* [it averaged 78 million between 2000 and 2007*], the number of hungry people and the infant mortality rate both decrease by half from their peaks, and new approaches to aging become economically viable.*
4. How can genuine democracy emerge from authoritarian regimes? *When strategies to address [humanitarian crises and other] threats are in place, when less than 10% of the world lives in non-democratic countries, when the number of armed conflicts (those with 1,000 or more deaths per year) diminishes by half, and when voter participation in most democracies exceeds 60% in most elections.*
5. How can policy-making be made more sensitive to global long-term perspectives? *When foresight functions are a routine part of most organizations and governments, when*

*national State of the Future indices are used in at least 50 countries, when the consequences of high-risk projects are routinely considered before they are initiated, and when standing Committees for the Future exist in at least 50 national legislatures.*

6. How can the global convergence of information and communications technologies work for everyone? There is no "challenge 6 will be addressed seriously when …", but the CD lists the *two most important targets as 'cost of Internet access becomes essentially free to users' and 'basic tele-education is free and available universally'*.
7. How can ethical market economies be encouraged to help reduce the gap between rich and poor? *When market economy abuses and corruption by companies and governments are intensively prosecuted and when the development gap – by all definitions – declines in 8 out of 10 years.*
8. How can the threat of new and reemerging diseases and immune microorganisms be reduced? The most important target for Challenge 8 shown on the CD is: *Life expectancy grows to 75 years with little disparity between nations*. Next in line are: *Effective global disease detection and therapy systems are in place*, and *vaccines and medicines for new diseases are usually developed within one month*.
9. How can the capacity to decide be improved as the nature of work and institutions change? *When the State of the Future Index or similar systems are used regularly in decision-making, when national corporate law is modified to recognize trans-institutional organizations, and when at least 50 countries require elected officials to be trained in decision-making.*
10. How can shared values and new security strategies reduce ethnic conflicts, terrorism, and the use of weapons of mass destruction? *When arms sales and violent crimes decrease by 50% from their peak.*
11. How can the changing status of women help improve the human condition? *When there is gender parity in school enrollment, literacy, and access to capital, when discriminatory laws are gone, and when there are essentially equal numbers of men and women in parliaments and cabinets.*
12. How can transnational organized crime networks be stopped from becoming more powerful and sophisticated global enterprises? W*hen money laundering and crime income sources drop by 75% from their peak*.
13. How can growing energy demands be met safely and efficiently? *When the total energy production from environmentally benign processes surpasses other sources for five years in a row, and when atmospheric* $CO_2$ *additions drop for at least five years.*
14. How can scientific and technological breakthroughs be accelerated to improve the human condition? *When the funding of R&D for societal needs reaches parity with funding for weapons and other purposes, and when an international science and technology organization is established that routinely connects world S&T knowledge for use in R&D priority setting and legislation.*
15. How can ethical considerations become more routinely incorporated into global decisions? *When corruption decreases by 50% from the World Bank estimates of 2006,*

*when ethical business standards are internationally practiced and regularly audited, when essentially all students receive education in ethics and responsible citizenship, and when there is a general acknowledgment that global ethics transcends religion and nationality.*

***The State of the Future Index***

The Index (SOFI) measures the 10-year outlook for the future based on the previous 20 years of historical data. It is constructed with key variables and forecasts that, in the aggregate, depict whether the future promises to be better or worse. A set of 29 variables was identified by an international panel of experts during a study conducted in 2006–07. Participants were asked to rate the variables, give worst- and best-scenario estimates, suggest new variables to be included in the SOFI, and suggest sources that could provide at least 20 years of historical data." (Glenn et al. 2008, p 6) Regional and national SOFI measures can – and should – also be constructed, and tutorials are on offer for this.

A box on page 6 of Gordon (2007) reproduced below contains a crude sketch of where humanity was winning or losing. The list may have changed as a result of the global economic crisis which was identified as a major source of deterioration in the 2009 state of the future report (see below).

| **Is humanity winning or losing?** | |
|---|---|
| ***Where we are winning*** | ***Where we are losing*** |
| **LIFE EXPECTANCY** | **$CO_2$ EMISSIONS** |
| **INFANT MORTALITY** | **TERRORISM** |
| **LITERACY** | **CORRUPTION** |
| **GDP PER CAPITA** | **GLOBAL WARMING** |
| **CONFLICT** | **VOTING POPULATION** |
| **INTERNET USERS** | **UNEMPLOYMENT** |

Development of the SOFI is assisted by "a relatively new and efficient method for collecting and synthesizing expert opinions, called the Real-Time Delphi." The method is web-based: it would not have been possible to develop it without email and the Internet. It eliminates time-consuming reliance on successive participant rounds as explained by Gordon (2007).

***Update to 2009***

The executive summary of the 2009 state of the future report (Glenn et al. 2009) begins as follows:

"Although the future has been getting better for most of the world over the past 20 years, the global recession has lowered the State of the Future Index for the next 10 years. Half the world appears vulnerable to social instability and violence due to increasing and potentially prolonged unemployment from the recession as well as several longer-term issues: decreasing water, food, and energy supplies per person; the cumulative effects of climate change; and increasing migrations due to political, environmental, and economic conditions.

The good news is that the global financial crisis and climate change planning may be helping humanity to move from its often selfish, self-centered adolescence to a more globally responsible adulthood. The G-20 is improving international financial regulations, market supervision, and accounting rules, and has brokered massive stimulus packages to prevent the world from falling into even deeper global financial crises. The December 2009 climate change conference in Copenhagen has focused attention around the world on the practical details of how to address climate change. World leaders in politics, business, academia, NGOs, and international organizations are increasingly cooperating. Many perceive the current economic disaster as an opportunity to invest in the next generation of greener technologies, to rethink economic and development assumptions, and to put the world on course for a better future.

After 13 years of the Millennium Project's global futures research, it is increasingly clear that the world has the resources to address its challenges. Coherence and direction has been lacking. But recent meetings of the U.S. and China, as well as of NATO and Russia, and the birth of the G-20 plus the continued work of the G-8 promise to improve global strategic collaboration. It remains to be seen if this spirit of cooperation can continue and if decisions will be made on the scale necessary to really address the global challenges discussed in this report.

According to the IMF, the World Bank, and OECD, the world economy should begin to grow again toward the beginning of 2010, but at a slower pace than during the past several years. If it is true that more complex systems tend to be more resilient than less complex ones, and that the world has increased in complexity since the Great Depression, the ability for the global economy to recover should be better today than in the past." (p 1)

A subsequent section of the executive summary addresses the question of how the world recession will change the future over the next 10 years compared with what it would have been like. Two indexes are presented; one without the recession and one based on an extended recession. The difference is quite striking: a stagnant or slightly declining SOFI if the recession is extended to 2020, compared with continued growth without the recession.

#### *Comment*

The ongoing work of the Millennium Project makes it one of the most valuable and reliable sources of information and analysis alongside the IPCC scenario work, and because it is specifically directed towards improving socioeconomic conditions with a focus on the world's poorest nations, it provides a better perspective on the dimensions of the global human condition. Moreover, the four scenarios developed within the project to some extent reflect the IPCC scenarios but also point the way forward to a set of futures that reflect greater detail.

### Evolution's Edge

#### *The message*

Graeme Taylor (2008) argues that the dominant global trend is towards *collapse* as world population growth and increasing consumption per head combine to exceed available global resources. Global energy shortages, climate change, growing water and food shortages are some of the indications. [8] An even worse threat than food shortages is the "mass extinction of life on Earth" as ecosystems degrade (p 51). He decries (p 59) the "poor vision of the rich world". The United Nations *Human Development Report* (2005, p 52) stated that the eight millennium goals which set quantifiable targets for 2015 to reduce world poverty and hunger, improve health and education, provide opportunities for women and protect the environment, lent themselves to policy responses rooted in technical and financial terms. "Ultimately, however, the real barriers to progress are social and political. They are rooted in unequal access to resources and distribution of power within and among countries."

Taylor quotes an Earth Policy Institute estimate that the worst social and environmental problems can be solved by increasing spending by approximately $190 billion per year. Even adding more ambitious goals not included in the $190 billion (such as the complete elimination of malnutrition, providing basic sanitation and eliminating deadly diseases such as malaria), it is unlikely to cost more than one percent of the world's GDP (p 60).[9] He also points to global military costs of $1.235 trillion, which appears to dwarf any cost needed to meet current basic human and environmental needs.[10]

There is a minor but emerging second global trend towards *transformation*, towards (a) sustainable development, (b) transformative material technologies (renewable energy, conservation, nanotechnologies, biotechnologies, computers and the Internet, whole-systems design and eco-design), and (c) transformation of ideas and social movements. Taylor's main thesis is that "the paradigm must be flipped": "Sustainable development is not

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[8] For example, Dukes (2003) has estimated the amount of carbon fixed and stored by photosynthesis that was required to form the coal, oil, and gas that we are burning today. Today's average gallon of gasoline requires approximately *90 metric tons* of ancient plant matter as precursor material. The fossil fuels burned in 1997 were created from organic matter amounting to over 400 times the net primary productivity (NPP) of the planet's current biota. He estimates that replacing the energy humans derived from fossil fuels with energy from modern biomass would require 22% of terrestrial NPP, increasing the human appropriation of this resource by about 50%.

[9] World GDP or Gross World Product (GWP) in 2007 was $54.3 trillion at official exchange rates (World Bank 2008). As at 18 December 2008, *The World Factbook* (CIA 2009) had GWP in 2008 at official exchange rates at $61.1 trillion and at purchasing power parity (PPP) at $69.6 trillion. CIA (2009) notes: "A nation's GDP at purchasing power parity (PPP) exchange rates is the sum value of all goods and services produced in the country valued at prices prevailing in the United States. This is the measure most economists prefer when looking at per-capita welfare and when comparing living conditions or use of resources across countries. The measure is difficult to compute, as a US dollar value has to be assigned to all goods and services in the country regardless of whether these goods and services have a direct equivalent in the United States (for example, the value of an ox-cart or non-US military equipment); as a result, PPP estimates for some countries are based on a small and sometimes different set of goods and services. In addition, many countries do not formally participate in the World Bank's PPP project that calculates these measures, so the resulting GDP estimates for these countries may lack precision. For many developing countries, PPP-based GDP measures are multiples of the official exchange rate (OER) measure. The differences between the OER- and PPP-denominated GDP values for most of the wealthy industrialized countries are generally much smaller."

[10] The total mitigation costs based on the Earth Policy Institute may represent too simplistic a view. Economic analysis elsewhere suggests that there may be savings as well as increased costs, and that timing is crucial with strongly rising costs more than likely to occur if quick action is not taken. The figure for military costs, however, is authoritative, coming from the Stockholm International Peace Research Institute (SIPRI). Updated statistics show global military costs rising by 6% to $1.339 trillion in 2007, to a level 45% above 1998 in real terms. The United States accounted for 45% of the global total in 2007, followed by the United Kingdom, China, France and Japan with 4-5% each. The strongest relative increase over the past ten years, however, was in Eastern Europe (+162%), with Russia accounting for 86% of this regional increase (Stålenheim et al., 2008).

yet the *organizing principle* of any country, much less the world system. This is because the global economy is organized around quantitative growth rather than qualitative development, and around competition rather than cooperation." (p 150)

Societal change takes place in two areas: in material technology and social organization (p 156). Four important areas of change are women's rights, peace, social justice, and the environment. All four areas are gathering strength. They are part of an emerging integral worldview: "In order to be sustainable, the global economy will have to be organized around a worldview that understands that human economies are subsystems of the environment." (p 170). That is the crux of the flipping paradigm, and Taylor is certainly not alone in his advocacy: most agree that living beyond the means of the capacity of the environment is unsustainable.

***Scenarios***

Taylor outlines three scenarios, summarized below from his own text (pp 203-206).

**1 Business-as-usual**. There is a real danger that the majority of political and business leaders in the world will fail to act quickly enough to preserve major ecosystems and prevent disaster. Their reluctance to make disruptive changes comes from a combination of ignorance, inertia and interests. Most policy-makers also believe that the constant expansion of industrial production and consumption is not only beneficial but also necessary for maintaining and improving living standards. The consequences of this worldview are that every country in the world considers economic growth to be more important than ecological conservation.

High commodity prices will make it profitable to exploit previously uneconomic resources such as marginal soils and difficult-to-access forests and minerals. This may meet growing demand for a number of years and continue the illusion that the global economy does not have to operate within biophysical limits. The consequences of ignoring the need to change our unsustainable economy will be an accelerating destruction of major ecosystems, and an accelerating rate of global warming. We will not be able to avoid major changes – but if we continue with business-as-usual we will ensure that when the changes come they will be catastrophic.

**2 Adjusting the existing system.** Most governments in the developed world are becoming increasingly aware of the dangers posed by climate change and environmental degradation. However, it is very difficult for politicians to make significant changes within the present economic and political framework. The usual response has been to try to gradually reduce the amount of environmental damage done by their economies. Because politicians must try to please voters who are concerned about the environment, without alienating environmentally polluting businesses or their employees, these policies are often contradictory.

The easy way out is to adopt politically expedient solutions. These often have dubious environmental and economic value.

**3 Transformational change.** The idea of completely redesigning society in order to preserve the environment strikes many people as both unnecessary and unrealistic. One CEO of an energy corporation claims that environmentalists' demands that his company stop building coal-fired power plants reflect a "snap-your-fingers, instant transition of the economy" mind-set. But as long as we have a worldview that believes that human economies exist outside of nature, we won't be able to accurately see either the problems or the solutions. Once we make a paradigm shift and begin to recognize that human economies are completely dependent upon their environments, preserving healthy ecosystems becomes an imperative. The question then is not whether we can afford to create an ecologically sustainable global system but what we have to do in order to quickly transform the industrial system and prevent irreversible global warming.

The new worldview makes it possible for the consumer society to be rapidly transformed into a conserver society because it challenges us to evaluate all economic and cultural activities in terms of how they support the transition to a sustainable society. Because the new paradigm is based on systems thinking, it helps people understand how issues are interconnected, to analyze problems and to develop solutions.

### ***Comment***

Taylor defines two trends: a dominant one towards collapse through unsustainable exploitation of the world's resources, and an emerging trend towards transformation which he is not confident will succeed. There is merit in pointing to these trends which are reflected in the description of his three scenarios, but the suggested solution fails to convince due to the demand for a complete societal redesign without adequately explaining how political, technological and economic factors can realistically help bring this about.

Taylor correctly shows that our ecological footprint is too large for the total resources of the planet (we are consuming fossil resources in a couple of centuries that took eons to develop, and are destroying ecosystem services that have also been built over a long time). He also validly points, as others have, to the relatively low cost of fixing the global social and environmental problems, though some other views on this are more nuanced. The weakness of his thesis is that he tends to ignore the reality of the political and economic forces and their capacity to help bring about a systems approach or "paradigm change". A plausible best-case scenario should be able to explain how this could happen.

## SIX DEGREES

### ***Our future on a hotter planet***

Mark Lynas (2008a) bases his book on IPCC's projected range of warming over the 21$^{st}$ century, from 1.4 to 5.8$^{0}$C between 1990 and 2100 (IPCC 2001, p 8). His first six chapters – the bulk of the book – describe in turn the "one-degree", "two-degree", "three-degree" worlds up to the "six-degree" world, a world that can only be described as terrifying. Lynas is a science journalist and author whose academic background is in history and politics. He calls his book "above all a work of synthesis, bringing together research conducted by many hundreds of scientists around the world." (p 9) The book received an important accolade by winning the £10,000 Royal Society science book of the year prize for 2008.[11] It has been described as *alarmist* by few and *alarming* by many, which indeed it is as it leads the reader through to the "six-degree" world.

The final chapter, "Choosing the future", starts by commenting on the disturbing trend in $CO_2$ emissions up to 2006 according to the Global Carbon Project, a trend that is reinforced by findings updated to September 2008. The scientists building the global carbon budget 2007, all from distinguished institutions[12], concluded (Canadell et al. 2007):

- Anthropogenic $CO_2$ emissions have grown four times faster since 2000 than during the previous decade, despite efforts by the Kyoto Protocol signatories to curb emissions. The growth is above the worst-case emission scenario of the IPCC.
- Less developed countries are now emitting more carbon than developed countries. China passed the US in 2006 to become the largest $CO_2$ emitter, and India will soon overtake Russia to become the third largest emitter.
- The carbon intensity (ratio of GDP to carbon emissions produced) of the world economy is improving more slowly than during previous decades.
- The efficiency of natural sinks has decreased by 5% over the last 50 years partly due to a 30% decrease in the efficiency of the Southern Ocean sink over the last 20 years.[13] The efficiency of natural sinks is expected to decline further, implying that the longer it takes to begin reducing emissions significantly, the larger the cuts needed to stabilize atmospheric $CO_2$.
- All these changes have led to an acceleration of atmospheric $CO_2$ growth 33% faster since 2000 than in the previous two decades, implying stronger climate forcing and sooner than expected. In parts per million, the annual increases were 1.3 in 1970-79, 1.6 in 1980-89, 1.5 in 1990-99, and 2.0 in 2000-07.

The project participants say that we are getting further and further away from the IPCC "stabilization pathways" outlined in the 2001 scenarios. Lynas comments: "Things do not look good." (p 270).[14]

The build-up of degrees of warming has already started as described in the initial chapter dealing with the current "one-degree world". Lynas reminds us that due to the thermal lag of the planet, even if all emissions of greenhouse gases implausibly were to stop overnight, temperatures will still rise between 0.5 and 1$^{O}$C. This is already threatening coral reef ecosystems which are close to their thermal limits, and it may be enough for the Nebraskan

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[11] *The Guardian*, 17 June 2008.

[12] The affiliations of the contributors to the global carbon budget were: The British Antarctic Survey, the Carbon Dioxide Information Analysis Center of the Department of Energy (CDIAC), the Carnegie Institution of Washington, the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia), NOAA, and the Woods Hole Research Center, whose director, John P. Holdren, became President Obama's science adviser.

[13] It is not clear how this relates to ocean acidification, which Lynas discusses in a separate context (pp 75-79).

[14] One outline of how reality is deviating increasingly from the 2001 'stabilization pathways' is a PowerPoint presentation by Malte Meinshausen (2004), of the Potsdam Institute for Climate Impact Research, whose director since the Institute was founded in 1992, Hans Joachim Schellnhuber, is also the German government's chief advisor on climate change.

dustbowl of the 1930s to return, and to cause further damage to already receding mountain glaciers. We are also steadily approaching a tipping point in the Arctic which could leave the polar area ice-free by 2040, with rising sea levels among the more direct effects.

Lynas observes that we have less than a decade to cut back emissions to avoid “dangerous” levels of warming but we can still aim for a “safe landing” on the one- to two-degree runway (p 270). This provides material for a first “Lynas scenario” (reinforced by a series of climate shocks in 2011-12 to reinforce the political will). [15]

He notes that in all fields of knowledge there are things we know we don’t know, and things we don’t yet know that we don’t know, as former Defense Secretary Donald Rumsfeld said in 2002 during a Defense Department briefing.[16] Discovering the “unk-unks”, as they have been dubbed by marketing writers,[17] is a challenge in scenario planning, whether in connection with climate science, socioeconomics, politics, or technological development.[18] Lynas finds that “emissions scenarios are actually a much bigger unknown than any of the much discussed climate change uncertainties that contrarians are always harping about.” (p 271) First, they depend on economics and politics rather than the more solid ground of physics – which is one of the reasons long-term emissions can probably never be accurately predicted. Dealing with this must be done in terms of “what if” – building scenario stories based on different assumptions about economic, political, societal, and technological drivers.

“The second known unknown is a genuinely scientific one: what academics call “climate sensitivity” (p 271). It is defined as the equilibrium temperature response of the planetary system to a doubling of pre-industrial atmospheric concentrations of $CO_2$. It is vitally important because if the climate is not very sensitive to carbon, high carbon emissions will lead to relatively manageable temperature rises – and *vice versa*. Meinshausen (2004) discusses this in terms of probabilities based on the comparison of different scenario studies that the average warming compared with pre-industrial levels according to a certain

[15] This scenario was developed independently of the third Stockholm Institute scenario described below. Both see action being galvanized by major climate scares. As it happened, Mark Lynas was on the team helping to build the Stockholm Institute scenarios (Domjan and Isyanova 2008, p 51). He describes this in an article in *The Guardian* (Lynas 2008b). Spratt and Sutton (2008), figuring later in this appendix, propose the ominous trigger that all the summer sea-ice in the Arctic melts in 2013 or before, and then again each following summer.

[16] The video transcription revealed the following succinct and quite elegant wording which deserves to be remembered without distortion: “There are known knowns. There are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don’t know. But there are also unknown unknowns. There are things we do not know we don’t know.” (http://en.wikipedia.org/wiki/Known_unknown)

[17] Mullins (2007).

[18] Allen and Frame (2007b) makes the following distinction in climate science. Known knowns represent climate model inputs where uncertainty is negligible. Known unknown model inputs are uncertain but correspond to directly observable quantities with a known, and testable, distribution, such as the rate of change in greenhouse-gas loading. Unknown unknown model inputs, which include structural choices, do not have a well-defined prior distribution. Sometimes called “nuisance parameters”, they are the bugbears; they are heavily dependent on sampling design, which is at the discretion of the particular investigators in charge of a particular climate model. The authors note that climate sensitivity has been non-linearly related to every observable aspect or feature considered to date, especially at the high end including the attempt to find parallels with LGM temperature (“last glacial maximum”). Lynas notes that “the gap between models and paleoclimate remains troubling” ( p 273), but new studies are filling the gap in a disquieting way, finding that research into paleoclimate may suggest that the upper limit of current climate sensitivity may be above six degrees (p 275).

stabilization path will eventually exceed 2$^{O}$C. A 550 ppm carbon-equivalent path ($CO_2$e) carries a 84% risk of this happening, compared with 52% for a 450 ppm path and 26% for a 400 ppm path. His probabilities were derived from analysis of 54 existing scenarios from the IPCC *Special Report on Emissions Scenarios* (Nakicenovic et al. 2000) and subsequent scenario work. Note that even the 400 ppm path is estimated to carry a 26% risk.

Meinshausen's analysis from 2004 is probably already outdated. He notes, for example, that to stabilize at 450 ppm, global emissions must be cut by 20-30% by 2050.[19] The cuts currently contemplated are much in excess of 20-30% by 2050. This development is in line with the observation that we are getting further and further away from the stabilization pathways envisaged by the IPCC based on Nakicenovic et al. (2000).

A more recent analysis by a team of prominent climate scientists headed by Malte Meinshausen confirms the above, and also shows that even if it may not always be stated explicitly, delay is more than likely to increase costs. The team (Meinshausen et al. 2009) analyzed a range of scenarios to find that halving global greenhouse gases by 2050 relative to 1990 yields a 12-45% probability of exceeding 2$^{O}$C by 2100. But it also found that the probability of exceeding 2$^{O}$C rises to 53-87% if global emissions are still 25% or more above 2000 levels in 2020. "Given the substantial recent increase in fossil $CO_2$ emissions (20% between 2000 and 2006 [according to Canadell et al. 2007]), policies to reduce global emissions are needed urgently if the "below 2$^{O}$C target" is to remain achievable."(p 1160)[20]

IPCC's fourth assessment synthesis report (IPCC 2007, pp 67-69) reflects this, as already summarized in the section on representative concentration pathways. To stabilize between 445 and 490 ppm $CO_2$e will require a reduction of emissions between 50% and 85% by 2050 relative to 2000. This will limit the increase in the average global temperature to 2.0-2.4$^{0}$C, and will require a peak year for emissions by 2015. Stabilizing at 490-535 ppm $CO_2$e will require 30-60% lower emissions by 2050, resulting in a 2.4-2.8$^{0}$C increase in global temperature. Emissions will need to peak by 2020 for this to happen. (p 67)

Stabilization paths at 445-535 ppm $CO_2$e can be achieved without drastic reductions in GDP. Generally, the more ambitious stabilization paths are not much more costly than those allowing for higher emissions: "There is *high agreement* and *medium evidence* that in 2050 global average macroeconomic costs for multi-gas mitigation towards stabilization between 710 and 445ppm $CO_2$e are between a 1% gain to a 5.5% decrease of global GDP. This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050. For specific countries and sectors, costs vary considerably from the global average." (p 69)

While climate models come up with a range of assessments depending on the detailed assumptions, the general consensus on climate sensitivity has been that a doubling of pre-industrial $CO_2$ levels from about 280 to 550 ppm may yield an eventual temperature rise of

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[19] But Meinshausen also found that delaying global action by 10 years doubles the reduction rates required by 2025. This provides strong encouragement for a call to action now, to avoid having to deal with much more expensive solutions in the future.

[20] The paper is also discussed in Appendix 4, dealing with limits to growth under global warming.

$3^0C$. However, Oxford University's climateprediction.net project, which involves thousands of people running a climate model on their home computers, came up with a wider range of climate sensitivities, up as high as $11^0C$. Project coordinator David Frame said according to Lynas (p 273) that this had "profound implications. If the real world response were anywhere near the upper end of our range, even today's levels of greenhouse gases could already be dangerously high."

Meinshausen's work on climate sensitivity illustrates the inherent difficulty in making precise "best estimates." Allen and Frame (2007a) suggest that the properties of the climate system we can observe now does not distinguish between a 4% and a greater-than 6% climate sensitivity. They say this is intuitively obvious because once the world has warmed by $4^0C$, the conditions will be so different from anything we know today that it is inherently hard to predict when the warming will stop.

Roe and Baker (2007) find that uncertainties in projections of future climate change have not lessened substantially in past decades because, in particular, the probability of large temperature increases is relatively insensitive to reductions in uncertainties associated with the underlying climate processes. We cannot use conventional measures to validate a probabilistic climate forecast of a one-off event. One-off extreme events can make or break a model. We may refer to them as known or even unknown unknowns but they are basically nonlinearities in the system caused by large forces working through feedback processes. Non-linearity leads to ambiguity (Allen and Frame 2007b). Outcomes are no longer clear-cut, which explains much of the discussion in current climate change literature.

But we can build some of these uncertainties into the alternative scenario stories.

***The six "worlds"***

In a way, the book itself is a collection of scenarios, one for each "degree" – but it stops short of specifying components other than the physical characteristics, that is, the socio-cultural, technological, economic and political factors helping to drive each "world". The following is a potted version of what might be the physical consequences of the one-degree to six-degree worlds (judging from more recent assessments the impact of the $CO_2e$ concentrations shown may by now look underestimated):

1. *One degree of warming* (zero chance of avoidance due to the thermal lag). The damage has already begun: coral bleaching, shrinking glaciers, Midwest dustbowl. The unexpectedly high Arctic melting rate has raised the specter of non-linear feedback – that the system can trip from one reality to another quite rapidly.
2. *Two degrees*: Still possible to avoid, or limit to a $2^0C$ rise, provided the tipping point for emissions happens by the mid-2010s (IPCC 2007), and emissions decline towards a 60% cut by 2030 and 85% by 2050. There is an estimated 75% probability that this scenario will stabilize $CO_2e$ concentrations at around 450 ppm ($CO_2$ at 400 ppm).
3. *Three degrees* (the typical stabilization level for most climate sensitivity models in past years): Back in 2000, scientists from the British Met Office Hadley Centre (Cox et al. 2000) pioneered research to show that carbon-cycle feedbacks would significantly accelerate climate change over the 21st century in climate models. Up to that time and

beyond, general circulation climate models generally excluded feedback between climate and biosphere. The system involves an ocean carbon-cycle model and a dynamic global vegetation model. The latter modeled the state of the biosphere in terms of soil carbon, and the structure and coverage of five plant types within each model (broadleaf and needleleaf trees, shrubs, and $C_3$ and $C_4$ grasses which have different photosynthetic systems). The result of including feedback was a large increase in the temperature at which the $CO_2$ level stabilizes.[21] Lynas's general conclusion is that two degrees may be the threshold at which carbon-cycle feedbacks kick in. Taking these into account increases the risk that we will rapidly approach three degrees if the $CO_2$e target is allowed to grow beyond 450 ppm (or less judging from recent assessments).

4. *Four degrees*: Even more than in the three-degree case, there is a risk of feedback effects shooting the temperature scale further upwards. "One of the most dangerous positive feedbacks of all is one that sees the effect of climate change in the Arctic ricochet around the rest of the planet with increasing force and destructiveness. Like the positive feedback from soils, this threat comes from the fact that global warming accelerates the release of greenhouse gases from the ground, thus further accelerating global warming in an ever tighter spiral." (p 210) The potential time bomb is that around 500 billion tons of carbon are currently estimated to be in permanently frozen Arctic soils. Once thawing begins, much of this carbon will begin to escape. It can either enter the atmosphere directly as $CO_2$ or through the action of anaerobic bacteria enter in vast quantities as methane, which is a more powerful though shorter-lived greenhouse gas than carbon dioxide. It is possible that the threshold for Siberian methane feedback will be reached as the three-degree world is left behind, leading to an accelerated path to four degrees.

5. *Five degrees* represents a new world – "one largely unrecognizable from the Earth we know today. The remaining ice sheets are eventually eliminated from both poles. Rain forests have already burned up and disappeared. Rising sea levels have inundated coastal cities and are beginning to penetrate far inland to continental interiors. Humans are herded into shrinking "zones of habitability" by the twin crises of drought and flood. Inland areas see temperatures ten or more degrees higher than now." (p 215)

6. *Six degrees* (quoting Lynas): "The current generation of climate models almost all stop short of simulating six degrees of warming by 2100. .. Instead, we must rely on sketchy

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[21] Cox et al. (2000) compared three models: (a) a standard general circulation climate model with prescribed $CO_2$ levels and fixed vegetation based on the then standard concentration scenario, IS92a (pre-SRES 2000), (b) an interactive $CO_2$ and dynamic vegetation but no direct effect of $CO_2$ on climate, and (c) a fully coupled climate/carbon cycle simulation.

The projected fully coupled model diverges rapidly from the IS92a concentration scenario. While previous models treated rising temperatures as a simple linear process, the model took into account that land and ocean systems would not remain static during rapid global warming but would themselves be affected by the changing climate. For example, vegetable carbon in South America begins to decline as the drying and warming of the Amazon basin initiates loss of forest driven purely by climate change, with no anthropogenic effect or change of land cover included at this stage. Then, around 2050, the land biosphere as a whole switches from being a weak sink for $CO_2$ to being a strong source. Other complex effects follow both in the land and ocean systems, too detailed for this note but eminently readable in the paper itself. Suffice it to say that Lynas concludes: "By 2100 global warming in the Hadley model rose from $4^0$ to $5.5^0$C, perilously close to the .. IPCC .. worst-case scenario. This is why my scribbled notes expressed such shock and dismay when I first read the paper back in 2000." (p 139) geological information about extreme greenhouse episodes in the Earth's distant past to light our way forward into this Sixth Circle of Hell." (p 241) "The end-Permian extinction [251 million years ago], it seems, took place at a time of rapid greenhouse warming." (p 252). "All geologists agree that the end-Permian crisis was the mother of all disasters. So what lessons might it have for us if our world heads toward six degrees of warming?" (p 259) "The planet can rapidly turn very unfriendly indeed once it is pushed far enough out of kilter. Today, vast volumes of methane hydrates are again lodged on sub-sea continental shelves, biding their time for the trigger of rising ocean temperatures. Just how far they can be safely pushed, no one can tell. Nor is there any reason to rule out ocean stratification and hydrogen sulfide poisoning as another possible disaster scenario. … ." (p 261)

***Comment***

Mark Lynas has made a major contribution by bringing together an extensive array of authoritative scientific findings. His endnotes (pp 305-328) show all his sources in a way that makes it fairly easy to check his findings. The findings we checked were vindicated from the literature cited and from other sources found while exploring particular points.

## THE STOCKHOLM NETWORK

***Background***

The publication, *Carbon Scenarios: Blue sky thinking for a green future,* was written by the Stockholm Network's Paul Domjan and Gulya Isyanova (2008). The London-based Stockholm Network describes itself as Europe's only dedicated service organization for market-oriented think tanks and thinkers. It spans almost 40 countries from Iceland to Georgia, Russia to Portugal, and over 130 think tanks.

CEO Helen Disney writes in the foreword: "Debate on climate change has now shifted decisively from science to policy, generating a new set of questions and challenges.

Think tanks have a unique ability to bring together on neutral turf people who would not otherwise meet. This "intellectual matchmaking" serves a concrete purpose of devising creative policy solutions. With this in mind, we launched our Carbon Scenarios project, bringing together a range of experts from the worlds of economics, technology, environmentalism, science and policy, to sketch some visions of the future." [22]

The Stockholm Network's carbon scenarios describe different possible futures that result from the differentiated substance and implementation of possible climate policies. "The purpose of these scenarios is not to advocate a particular type of response, but rather to provide a non-partisan platform for building consensus around action that is deemed both necessary and possible. Unlike potentially partisan policy analysis, scenarios provide a framework to enable those from across the political spectrum to discuss the issue based not on what they would like to see happen, but rather on what potentially could happen." (p 3)

[22] The workshop included Mark Lynas, who has written about the Stockholm Institute project (Lynas 2008b).

It began by framing "success" in the same terms as the European Union and the UK government have done to date: to have a greater than 90% chance of less than 2$^{O}$C of warming above pre-industrial levels. The question was then asked: what can technology alone do and how quickly? Having mapped the possibilities offered by technological mega-trends on their own, the group then turned to climate science to ask what reduction in emissions was needed to achieve this "success".

It was decided that emissions will need to peak within the next 10-15 years, and that technology on its own is highly unlikely to provide this level of reduction in emissions. In other words, low carbon technology is insufficiently developed at this stage to be able to put us on the right track in terms of global emissions on its own – there was therefore a need to focus on the crucial role that policy plays in this matter.

More specific actions are assumed in these scenarios for the next few years than is normally the case. As the actions were imagined in a 2008 perspective, the comments on the Stockholm Institute scenarios must take account of what happened since: the global economic crisis, the failure of proposed emissions trading scheme legislation in the US, and the failure of COP-15, the Copenhagen UNFCCC conference in December, to produce a binding agreement.

The group identified the following drivers of climate policy, mainly up to 2015, to which comments have been added based on known events up to early 2010:

- A new global agreement for a post-Kyoto framework would provide an opportunity to rethink climate policy in light of both improved scientific understanding of climate change and the policy lessons of the Kyoto structure, the European Union Emissions Trading Scheme (ETS), and other regional, national and local schemes. Such hopes have faded at least temporarily after COP-15, and following the Obama administration's failure to put ETS legislation through Congress in 2009. This raises the point whether alternatives to emissions trading schemes are more likely to succeed, first at national, than at international level. This is discussed in the final section of Appendix 5, "Lessons for climate change policy from recent events."
- Tension between the developed and developing countries has been a permanent feature of UNFCCC negotiations. While most greenhouse gas emissions have come from developed countries, developing countries have the most to lose, because they are the most exposed to the consequences of a changing climate and may have to forego economic growth in order to avoid greenhouse gas emissions. But developing countries, especially China, account for the bulk of anticipated future emissions growth. These issues remain highly relevant, including the question whether developed countries will agree on a wealth transfer to the developing countries to fund mitigation and adaptation. It is hard to imagine a global solution that will be accepted by developing countries that does not include a credible guarantee of wealth transfer. The initial signs from Copenhagen are positive, with as yet unconfirmed commitments from the industrialized world to assist developing countries starting at a total $30 billion for 2010-12 growing to $100 billion-plus by the end of the decade.

- There is an ongoing tension between climate policy as a political project discussed by world leaders and as an expression of popular sentiment. The balance between seeing climate policy as an elite project and a popular project will have a major impact on the nature, degree and success of implementation of climate policy. The importance of this became abundantly clear during 2009 as climate change deniers began to dominate opinion pools and the attitudes of elected politicians.

- Historically high energy prices will continue for the foreseeable future (following the economic downturn). One key issue is whether these prices will benefit green technologies (renewable energy sources, energy efficiency measures, perhaps nuclear technology), or whether unconventional sources of oil with much higher environmental costs, including substantial carbon emissions during their production, will benefit. This includes oil sands, oil shale, deep-sea oil exploration, and first-generation biofuels using food plants for feedstock.

- The involvement of the US and China in international climate policy according to the Stockholm Institute report is a pre-requisite for any effective global solution. Analysis of the Copenhagen conference yields the same general conclusion.

- Stochastic weather events (cyclones, droughts, floods, hurricanes, cold spells and heat waves) will play a large role in people's perception of the urgency and need of addressing climate change, with direct consequences for their willingness to pay a short-term cost to do so.[23] Cold spells during 2009-10, culminating in the coldest northern winter for decades, probably had a negative rather than positive effect on perceptions.

While building these scenarios, three key policy lessons emerged: (1) the likelihood that climate change policy will fail to meet the criteria for success defined above, (2) the risks inherent in the UNFCCC process which drives the ongoing international negotiations (especially the annual "COP" conferences), and (3) the importance of wealth transfer.

Worryingly, none of the three policy scenarios meets the criteria for "success." Using emissions modeling by the Stockholm Network on the basis of IEA Reference and Alternative Policy Scenario emissions models, the Met Office Hadley Centre used a simple climate model to project likely temperature rises to 2100 for all three scenarios. All the scenarios had a likelihood of less than 90% that global average temperature increase would remain below $2^{O}C$.

***The three Stockholm Network scenarios***

All three scenarios started in 2008-09 from the same premises, and then outline actions up to 2015 but no further. In summary, the premises were:

- The incoming US president, not yet identified when the report was written, is crucial as nothing substantial will be agreed upon without the US.

[23] "Stochastic" has been defined as "of, pertaining to, or arising from chance; involving probability; random" (http://www.yourdictionary.com/stochastic). In the climate context, it implies that the events are large and highly visible, as well as random and unpredicted, and that they trigger non-linear feedback effects in the models.

- European governments are unable to pursue the nuclear option due to public opposition, and begin investing in green technologies such as wind, solar, and wave, as well as R&D and commercialization of what is considered "as yet unproven technologies" such as carbon capture and storage.
- There is substantial private investment in green technologies, but this is hampered by uncertainty about future carbon prices and some fear that a "green bubble" similar to the "IT bubble" is starting to grow.
- Continued economic growth was expected when the premises were defined, which explains the following: Oil prices remain high in 2009. The global economy manages to absorb the costs of high energy prices and what carbon regulation already exists. High oil prices are no longer seen as an impediment to global economic growth, as growth has continued despite five years of high oil prices.
- Erratic climatic events help galvanize favorable public opinion (as it turned out, an unusually cold winter in the US and Europe fed opinions that man-made climate change doesn't exist), and it becomes increasingly clear during 2009 that a decision on a post-2012 global response needs to be taken in Copenhagen (which didn't happen).
- Along with public calls for action on climate change, the situation in 2008 gives political decision-makers a sense of confidence. If the economy has managed to absorb these unprecedented costs unscathed, it could be pushed further. Business and industry also keep urging policymakers to harmonize climate change regulation and establish a framework for a global carbon price to enable them to make long-term investment decisions that are carbon price dependent. Before the Copenhagen conference, representative bodies and consortia lobby key governments and international organizations arguing that a global economy needs a global policy framework and a global carbon price. At this point, the three scenarios diverge.

**Scenario 1: Kyoto Plus**

This scenario looks at one possible elaboration of success in the current policy context: a process that leads to a global cap on $CO_2$ emissions being put in place in 2012. It attempts to answer the following questions: (a) How plausible is it that current policy continues in a positive direction and continues to gather pace? (b) Is there sufficient impetus in current trends for decisive action to be taken? (c) Will the ultimate outcome of current policy be sufficient to have a greater than 90% chance of less than $2^{O}$C of warming above pre-industrial levels?

In mid-2009, the US Congress adopts a domestic cap and trade scheme with strict quotas that apply to most of US industry. The scheme is due to start operating in 2012.

Based on this, the US president voices strong support for a global cap-and-trade scheme. After a new global scheme to succeed Kyoto emerges in principle from the Copenhagen conference, the details for the new scheme are agreed in 2010 and 2011. These include two successive five-year global carbon budgets for 2012-2022 (with some concessions including allowing China to start off with only voluntary caps despite being the world's largest emitter of $CO_2$); creation of a technology committee to assess each country in terms of appropriate renewable technologies and to designate it a corresponding amount from permit sales to spend on these technologies; and setting up an adaptation committee to evaluate financial assistance based on need and vulnerability.

The global cap is put into place at the end of 2012 and picks up pace from 2013, when it starts to gain stronger institutional identity. Although there is some minor political wrangling along the way, with some developing countries still getting more emissions as an incentive to remain in the scheme, and despite some other teething difficulties, the scheme is judged to be a success.

At the 2015 UNFCCC conference, ministers accept a 2022 deadline for agreeing on a new methodology for long-term national emissions quota allocation, as this is still being brought up at UNFCCC conferences by a large number of developing countries. However, not all participating countries are in favor and it is unclear at this stage whether the transition to an agreed long-term methodology will be politically viable, even by 2022.

**Result:** Global average temperature has a greater than 90% chance of rising by up to 3.31$^{O}$C above pre-industrial levels by 2100. This figure, like those calculated for the other scenarios, is based on emissions modeling by the Stockholm Network and climate modeling by the Met Office Hadley Centre.

**Scenario 2: Agree & ignore**

This scenario also looks at the current policy context but projects a different path from the one outlined in Kyoto Plus. Instead of focusing on the positive momentum present in the current context, it examines the stages at which this momentum can stall and backslide. Indecision and disagreement over the details of a post-2012 agreement play a crucial role in initiating a process of stalling and backsliding. These tendencies are compounded from 2012 onwards with implementation failures. The scenario tries to envisage what would occur if an international agreement ‘talked the talk’, but didn’t ‘walk the walk’.

Mid-2009 appears to signal that change is finally in the air when the US Congress passes a domestic cap-and-trade scheme (this didn’t happen). It is due to come into operation in 2012. However, the more nationalist and skeptical elements in the legislature ensure that the scheme lacks the strict quotas for which many environmental campaigners had hoped.

Despite the shortcomings of the domestic scheme, the American president voices support for a global cap-and-trade system. A new framework to succeed Kyoto in 2012 is finally thrashed out at the December 2009 conference in Copenhagen – an international agreement on a global cap results from tense negotiations.

Over a series of follow-up meetings in 2010 and 2011, the details of the scheme are hotly debated and contested. No significant progress is made towards agreeing on a framework for transferring funds (generated through permit auctioning) for financing the adaptation strategies of developing countries.

Although the world’s overall cap level has been decided and two provisional 5-year carbon budgets have been worked out, participants are unable to reach agreement on specific national carbon allowances. Some countries accept the provisional targets, others do not.

The US scheme successfully comes into operation in January 2012. However, the politics of implementing the scheme prove more divisive than expected, and a divide emerges between one camp, supported by President Obama[24], which sees the national scheme as a stepping stone to an integrated international scheme, and another, led by the Republican presidential candidate in 2012, that argues that the US must not yield sovereignty to an international body and must keep climate change policy implementation at home. In the course of a bitterly fought contest, the president narrowly loses the election.

After the global cap comes into force at the end of 2012, more problems emerge. There are cases of continued foot-dragging by some governments, which fail to meaningfully implement their national carbon cap and continue to insist on overly large allowances. The argument most often put forward is that economic growth still takes priority over climate change in many developing countries. Many countries thus avoid the cap and do not force their industries to accept carbon pricing.

As a result, parties that intend to stick to their targets face increasing domestic lobbying from business, which is seeking compensation for increased costs and lost international competitiveness. Business is skeptical that the international agreement will be enacted in a meaningful way and decides to focus on lobbying at the regional level, where, depending on location, it has obtained some degree of certainty.

**Result**: Global average temperature has a greater than 90% chance of rising by up to 4.85°C above pre-industrial levels by 2100.

**Scenario 3: Step change**

Like the other two scenarios, this one takes the current policy context as its starting-off point and assumes that developments already in motion continue until 2009. But “Step change” looks at the possibility of developments taking a radically different course.

IPCC (2007) indicated that the most perceptible manifestation of climate change that we are likely to witness in the short term is an increase in the severity and frequency of what is termed ‘extreme events’. Weather events such as heat waves, hurricanes, floods and droughts, which are statistically rare, will become less so. This prediction is taken as the impetus for a radical policy step change in the scenario.

This scenario is driven, first, by the simultaneous onslaught of several extreme events, and secondly, a quick and straightforward international response. We are considering the best possible solution to the worst possible problem.

As the December 2009 conference in Copenhagen comes to a close, the international community is relieved. The conference is deemed a success as it has resulted in an international agreement on a global cap. While the agreement resolves the issue of differential economic development with a graduation structure, a series of meetings needs to take place over the following years to establish the details and the practical side of the agreement. However, these meetings are increasingly framed by a series of accentuated climatic developments.

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[24] Obama’s win of course wasn’t known in early 2008. The source merely talked about ‘the president’. It wouldn’t be terribly useful to explore whether the scenario would have had better or worse chances with alternative candidates (Clinton, McCain or for that matter any of those who stood for candidacy from either party in early 2008 and had not yet been eliminated from the race).

These events include:

- Successive hot summers in 2009 and 2010 in Europe, hotter than 2003.
- The Indian subcontinent continues to experience a heavy and long monsoon season, leading to serious flooding and loss of life, especially in Bangladesh. High temperatures and low rainfall cause several crops to fail in Africa. As a result, many parts of the Indian subcontinent and Africa experience famine.
- Although these humanitarian crises receive media coverage in the West, they vie for attention with a much documented acceleration in the disappearance of sea-ice in the Arctic, which is now being projected to be completely gone by 2025.
- What really brings a new sense of urgency to the agenda are events in the US and China, which this time experience the brunt of nature's force. Like the European continent, North America experiences an unprecedented heat wave that leads to deaths in the thousands and ongoing blackouts across the Eastern seaboard. Meanwhile, in China a super-typhoon severely damages the port infrastructure at Shenzhen, while the smaller port at Fuzhou (in Fujian province) is almost entirely destroyed by another.
- 2011 brings more of the same.

These very visible and consistent indications of a changing climate, their immediate social costs and the inadequacy of current policy all act as an impetus for governments, and leads the US and China to take immediate and drastic action on national security grounds.

The US and China are motivated by two things. First, there has been a perceived failure by existing institutions and frameworks to both prevent and contain the damage. Second, both want to focus on developing a framework for action that is simple and can be implemented quickly.

Neither can afford to sit back and experience another summer like the previous two. While the Europeans are taken aback by the new interest from what they have seen as two traditional foot-draggers, the push for action is broadly welcomed by international business, which now recognizes that some form of major carbon regulation is coming and seeks a framework that is clear, universal and transparent.

On the basis of Sino-American cooperation, the December 2011 UNFCCC conference sees a major new climate change treaty signed, but the so-called International Climate Treaty has a very different structure and a much greater reach than anything observers had expected. It introduces a one-year phased transition from existing emissions-based trading schemes to a single global carbon production trading scheme. This scheme places a cap on the global production of carbon, whether in the form of oil, gas or coal, and shifts enforcement and permit auctioning from billions of individual emitters to a small number of firms that produce fossil fuels. This source-focused approach is expected to translate into changes on the demand side, with high energy prices acting to provide a very clear signal to business to invest in reducing demand and to provide alternatives.

For the first time, business is presented with a clear, long-term framework that promises a significant global carbon price regime which allows investors and entrepreneurs to focus more on new energy sources and increasing the efficiency of existing energy usage. The funds generated by the scheme supports research, adaptation and catch-up mitigation in the developing world, and also creates incentives for innovative mitigation in the developed world.

**Result:** Global average temperature has a greater than 90% chance of rising by up to 2.89°C above pre-industrial levels by 2100. While better than the two other scenarios, it still fails to meet the $2^0$C target which the scenario planners hoped for.

***Comment***

The Stockholm Network scenarios show three different possible developments from the same current situation in 2008-09. The scenarios are quite detailed and "nuts-and-bolts", and more difficult to summarize than other scenario stories.

In the cold light of recent events, some of the scenario premises are also plainly wrong, and may become more so over the coming few years. Emissions trading schemes, whether national or international, may have been dealt a deathly political blow by the legislative processes in 2009. Other policy models may be emerging, as discussed at the end of Appendix 5, which suggests that emissions policies may be more directly aimed at particular industries with any emissions trading schemes being limited to, say, the power generating industry. The US climate legislation being drafted in early 2010 contains such characteristics.

While an unduly detailed approach may cause a scenario to lose some credibility, as when a central feature of the assumptions such as the introduction of measures of direct manipulation of specific carbon-intensive industries in favor of general emissions trading schemes, the general principle of addressing specific events as a basis for scenario-planning is not invalidated. The Stockholm Institute scenario stories would be written differently today, but the comparative analysis of the three scenarios is still valid in principle.

It is more problematical that the event horizon is as close as 2015, and it is unclear how the path towards ultimate warming, which presumably formed the basis for the Met Office emissions analysis, is defined through the rest of the century.

A true scenario development would incorporate further actions as events unfold – actions driven by economic, environmental, social and technological forces, and a broader range of political forces. It would also attempt to assess the influence of physical feedback processes in more complex climate models (pioneered by the Met Office itself), because these themselves could feed back to and change the social, economic and political environment, and probably provide further technological pointers as well.

## SHELL'S SCENARIOS TO 2050

### *Shell and the 1973 oil crisis*

Royal Dutch/Shell pioneered scenario planning as a management tool. As conventional forecasts from the mid-1960s onwards increasingly failed to support strategic planning efforts, scenario analysis was introduced as a way to plan without having to predict things that everyone knew were unpredictable (van der Heijden 1996, p 16).

In the early 1970s, the main item on Shell's agenda was the price of oil, but the outlook for worldwide demand was not considered an issue – it had been growing steadily since the end of World War Two by around 6% every year. Shell's scenario planners, however, looked beyond the simple model and found that the governments in the major oil-producing countries were starting to establish their authority, and they wondered whether it would continue to make sense for these governments to supply the increasing quantities required by the oil companies. They concluded around 1970 that this was sufficiently uncertain to make it worth developing a "crisis scenario" in which the producing countries would refuse to continue to increase production to meet the oil companies' demand.

Shell's scenario analysts put the company on a thinking track where traditional forecasting would never have taken it. They demonstrated that scenario planners interpret information from the general environment differently from others around them. Over the rest of the 1970s, general industry inertia caused refining capacity to run into oversupply as demand ceased growing – but due to Shell's early adaptation of alternative policies the company suffered much less from overcapacity and outperformed the industry by a long margin (pp 17-19).

It is appropriate, therefore, to consider how Shell's continuing scenario planning effort views the possible worlds for which the company is planning.

### *The setting of the Shell scenarios*

The current source is *Shell Energy Scenarios to 2050* (Shell 2008). The website also provides access to past scenarios since 1992 to show the changes in the company's strategic thinking.

The basic premise for the current scenarios is unequivocally stated at the outset: "Never before has humanity faced such a challenging outlook for energy and the planet. This can be summed up in five words: "more energy, less carbon dioxide"."

The world, in an era of revolutionary transitions, can no longer avoid three hard truths about energy supply and demand. These truths apply in a situation where the world population has more than doubled since 1950 and is set to increase to 9 billion by 2050. History has shown that as people become richer they use more energy. Population and GDP will grow strongly in non-OECD countries and China and India are just starting their journey on the energy ladder. These are the hard truths:

- *Step change in energy use*: Developing nations, including China and India, are entering their most energy-intensive phase of economic growth as they industrialize, build infrastructure, and increase their use of transportation. Demand pressures will stimulate alternative supply and more energy efficiency — but this may not be enough to offset growing demand tensions. Disappointing the aspirations of millions by adopting policies that may slow economic growth is not an answer either — or not politically feasible.
- *Supply will struggle to keep pace*: By 2015, growth in the production of easily accessible oil and gas will not match the projected rate of demand growth. While abundant coal exists in many parts of the world, transportation difficulties and environmental degradation ultimately pose limits to its growth. Meanwhile, alternative energy sources

such as biofuels may become a much more significant part of the energy mix — but there is no "silver bullet" that will completely resolve supply-demand tensions.

- *Environmental stresses are increasing*: Even if it were possible for fossil fuels to maintain their current share of the energy mix and respond to increased demand, $CO_2$ emissions would then be on a pathway that could severely threaten human well-being. Even with the moderation of fossil fuel use and effective $CO_2$ management, the path forward is still highly challenging. Remaining within desirable levels of $CO_2$ concentration in the atmosphere will become increasingly difficult.

***Two possible ways forward***

*Scramble* and *Blueprints* are Shell's current scenarios. The company recognizes that neither is ideal, though some outcomes will be better than others. While technology will provide some answers, political and social choices will be critical. *Scramble* represents a more reactive approach, focusing on increasing energy supply first and facing the consequences later. In *Blueprints*, the difficult decisions are taken sooner rather than later, leading to revolutionary changes and a better balance of economic and environmental needs. Shell believes the environmental, humanitarian and economic outcomes seen in *Blueprints* make it a better, more sustainable world than *Scramble*.

The timeline provides a convenient framework for comparing the two scenarios decade by decade to the end point in 2050:[25]

- 2015: *Scramble*: Flight into coal; rapidly growing $CO_2$ emissions. *Blueprints*: Worldwide emissions trading scheme evolving post-Kyoto. Coalitions emerge around the world to address local pollution problems and cooperate to find solutions. Increasing realization that changes are not necessarily painful relieve fear and more substantial actions become politically feasible.
- 2020: *Scramble:* Demand for transport fuels leads to huge focus on biofuels. Substantial rises in food prices follow, especially in countries that have corn as a staple. Interest next grows in advanced technology biofuels that help address sustainability concerns. *Blueprints:* Global $CO_2$ trading scheme with incentives and taxation is designed to reduce energy consumption and $CO_2$ emissions. Increased alignment on $CO_2$ pricing slows demand for coal, stimulates energy conservation and investment in clean energy technologies.
- 2030: *Scramble:* The world's infrastructure for coal transportation reaches its limits. It is no longer possible to move enough coal round by sea or rail to meet the world's needs. *Blueprints:* From 2020, $CO_2$ pricing and the cap-and-trade system pave the way for $CO_2$ capture and underground storage (CCS). A crucial transition technology from today's high-carbon energy system to tomorrow's low-carbon system. – Electric vehicles hit mass market. Bowing to public pressure, governments set targets for reduced emission and zero-omission vehicles and reward companies who meet them.

[25] http://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/dir_global_scenarios_07112006.html.

- 2040: *Scramble:* Nuclear power helps offset demand for coal, but not as much as expected. Plants take a long time to build and can be politically controversial. Nuclear power will not be able to contribute meaningfully until 2050. *Blueprints:* Electrification of transport sector. By 2040 20% of coal power plants have CCS applied and 50% of new vehicles are electric or hydrogen.
- 2050: *Scramble*: Climate adaptation measures begin. Eventually people demand energy efficiency measures, and governments finally take steps. Energy related $CO_2$ emissions decline, but atmospheric concentrations continue to rise. The world needs about 15% less energy than if it had not acted. Having avoided taking hard decisions earlier, the world now faces expensive consequences in 2050 and beyond, legacy of a reactive, scrambled approach. - *Blueprints*: Decoupling of world GDP and energy growth. By the 2050s the world is using about 25% less energy per capita than today. Chinese energy use has also peaked, though India is still climbing the ladder. – By 2050, 60% of electricity comes from renewable resources. CCS means fossil fuels are used in more environmentally friendly ways. – Though energy use will be much higher than it is now, it will be 26% lower than if no action had been taken, and the path is much more sustainable. There will be three billion more of us, but $CO_2$ emissions will be lower per capita, a major benefit of pursuing *Blueprints*.

The scenarios are accompanied by quantitative estimates of key variables, including the primary energy sources (oil, gas, coal, nuclear, biomass, solar, wind, and other renewables).

***Comment***

There is no reason to doubt Shell's sincerity in producing these scenarios, which continues a long history going back to the company's pioneering efforts in the late 1960s. The scenarios naturally focus on energy, but so do other scenarios reported in this chapter. They are credible but may not quite match the greater urgency climate scientists are now advocating.

Shell may have been right at the time that emissions trading schemes were the way forward, but the failure to be nationally legislated and globally recognized in 2009 may lead to other solutions, as discussed at the end of Appendix 5. ETS may of course be revived, but it no longer seems to be the only way towards reducing $CO_2$ emissions in future decades.

## ECONOMISTS' VIEWS OF THE FUTURE

Scenario planning is not part of all climate change reviews. Many, however, contrast a future which would eventuate without proper action, with a future where action is taken. We have dubbed these sorts of choices "binary scenarios": if we continue "business-as-usual" and fail to act the binary value is zero; if we heed the advice of the particular investigation and proceed towards a "best case", the binary value is one.

Three economic reports discussed here fall into the sphere of 'binary scenarios': the British report on the economics of climate change by Nicholas Stern (Stern 2006), the final report to the Australian government by Professor Ross Garnaut (Garnaut 2008a), and the book *Common Wealth: Economics for a crowded planet,* by the special adviser to the United Nations Secretary-General Ban Ki-moon on the Millennium Development Goals, Professor

Jeffrey Sachs (2008). Spratt and Sutton's *Climate Code Red* (2008) is another important analysis, again with a best-case scenario contrasted with a truly bleak BAU scenario.

## STERN REPORT ON THE ECONOMICS OF CLIMATE CHANGE

***Notes on the reception of the report***

The Stern *Review* (Stern 2006) is 700 pages long, but the future implications are documented in the executive summary, which essentially distinguishes between a '' future and what has to be done if we are to rectify the problem. Stern has also since the *Review* updated his views in *A Blueprint for a Safer Planet* (2009).

Before reporting Stern's views on the future, we need to record that his approach and assumptions received some fairly immediate criticism, led by two prominent economists. They has served to put his key conclusions into perspective and the very public debate has probably helped consolidate the status of the Stern review.[26]

William Nordhaus (2007a) argued that most studies of climate change economics have found that "efficient" or "optimal" economic policies to slow climate change involve modest rates of emissions reductions in the near term, followed by sharp reductions in the medium and long term." He calls this the *climate-policy ramp*, in which policies to slow global warming increasingly tighten or ramp up over time. It means moderate climate policy now, tightening emissions slowly in the beginning and then faster as time goes.

Nordhaus's second point concerns Stern's choice of a low social discount rate which benefits future generations and helps minimize uncertainty and the risk of non-action. It relates to the ramp issue. Stern's radical departure from the work of other economists according to Nordhaus arises because the discount rate is set as low as 0.1%, based on the ethics of achieving intergenerational neutrality (which Nordhaus also queries). "This magnifies enormously impacts in the distant future and rationalizes deep cuts in emissions, indeed in all consumption, today. With a higher discount factor we would be back at the ramp."

Sir Partha Dasgupta (2006) was the other prominent critic of the 2006 *Review*. His concern was Stern's distribution model (1) between present and future generations (which he called 'delta', though it seems to be normally annotated by another Greek letter, $\rho$ (rho)) and (2) between individuals regardless of when they appear on the scene ('eta', $\eta$). He agreed with

[26] The review gave rise to a vast number of both positive and negative criticisms, as listed, for instance, by Wikipedia (http://en.wikipedia.org/wiki/Stern_Review#Positive_critical_response (accessed 31.1.09)). "Some critics, particularly economists, argued that Stern had overestimated the *present value* of the costs of climate change, and underestimated the costs of emission reduction. Others, particularly associated with business, argued that the economic cost of the proposals put forward by Stern would be severe, or that the scientific consensus view on global warming, on which Stern relied, was incorrect. By contrast, a number of critics, particularly natural scientists, criticized Stern from the opposite direction, arguing that he had underestimated the costs of damage to natural environments from climate change, and that more aggressive action to stabilize climate was needed." Many of the criticisms, of course, were of a political nature.

the former, reflected by the low social discount rate which gives egalitarian weights to the present and future. He noted that other economists think otherwise, including Nordhaus.

Dasgupta's problem was with the second parameter in the model (eta), technically defined as the elasticity of the social benefits attained, or the social marginal utility. While Stern adopted a very egalitarian attitude across the time dimension (low time discount rate), Dasgupta says he adopted the opposite stand with regard to the well-being across people when futurity is not the issue – for example when comparing the well-being of rich and poor in the contemporary world. He notes (p 4): "As the numerical figures that are assumed for them influence estimates of the economic costs and benefits of controlling carbon emissions, enlarging sequestration possibilities, and investing in alternative energy technologies, delta and eta are hugely significant parameters."

Dasgupta elaborates (p 7): "To assume that eta equals 1 is to say that the distribution of well-being among people doesn't matter much, that we should spend huge amounts for later generations even if, adjusting for risk, they were expected to be much better off than us." He then shows that the two model parameters give unrealistic results for the savings rates needed to cater for future generations. "What should be expected from the Review is a study of the extent to which its recommendations are sensitive to the choice of eta. (Many economists would expect a sensitivity analysis over the choice of delta too.)" (p 8)

Wassilis von Rauch (2008) of the prestigious Potsdam Institute for Climate Impact Research investigated the issues in his diploma thesis. He notes (p 2): "The novelty of Stern's modeling results is that they justify early and strong climate policy (i.e. mitigation of greenhouse gas emissions) on economic grounds. This is contrary to the … climate policy ramp, which suggests that little mitigation efforts now and stronger action in the future is economically favorable." Accordingly, the main question for von Rauch is whether Stern's opposition to the climate policy ramp is defensible.

He concludes (p 60): "In my view, despite [some justified] critique against Stern's modeling, his approach takes a big step forward compared to previous studies. It takes into account (some of) the uncertainty related to climate change, showing that it is misleading to argue about the optimal path of emissions, as if this was a determinable option. In the *Review*'s terms, climate policy is .. about what future risk we are willing to accept (and in a second step, how we can avoid too big risks in a cost-effective way). This approach is backed up by the fact that best- and worst-case impact estimates differ by several orders .. . The fact that Stern does not account for uncertainties about future greenhouse gas emissions by using different SRES scenarios and that he doesn't consider the recent upper extremes of climate sensitivity estimates .. implies that the range of results could arguably be even bigger." "It seems very likely that the trend in climate policy assessment following the Stern Review will prescribe what Stern initiated: A risk analysis concerning the impacts of climate change finding maximum tolerable levels of greenhouse gas concentrations and following this an analysis of cost effective ways to get there."

A defense against Nordhaus's criticism in particular can be found in a *Science* article dealing with the treatment of risk and ethics in the Stern report (Stern and Taylor 2007). The comments are directed towards a second critique by Nordhaus (2007b), this time aimed at both the parameters in Stern's economic model, the time discount rate and the social marginal utility.[27] "Analyses are sometimes divided between the "descriptive approach," in which assumed discount rates should conform to actual political and economic decisions and prices, and the "prescriptive approach," where discount rates should conform to an ethical ideal, sometimes taken to be very low or even zero." (p 202) Nordhaus concludes:

"The Stern Review's unambiguous conclusions about the need for urgent and immediate action will not survive the substitution of assumptions that are consistent with today's marketplace real interest rates and savings rates. So the central questions about global warming policy – how much, how fast, and how costly – remain open." (p 202)

Stern and Taylor (2007) respond that the Stern results were driven not just by ethics but also by risk. "The modeling in the Stern Review is valuable in identifying some key drivers of costs and benefits in terms of economic modeling approaches, scientific variables, and ethical considerations. However, excessive focus on the narrow aspects of these simplistic models distorts and often exaggerates their role in policy decisions. They cannot substitute for the detailed risk and cost analysis of key effects." (p 203) As the scenario literature shows, simple climate models are now regarded as inadequate because they ignore nonlinear feedback effects. Stern apparently extends this finding to a broader range of models.

The authors say that the ethical approach in the analysis focuses on the ethics of allocation between richer and poorer people ('eta') and between those born at different times. In terms of the discussion above, the standard social welfare discounting formula includes both the time discount rate, $\rho$, and the elasticity of the social benefits attained (social marginal utility, $\eta$). They defend the use of a low discount rate based on the very long perspective taken in climate change research, as distinct from commercial projects. As far as increasing social benefits are concerned this would involve sizeable beneficial transfers: "Although it is a tenable ethical position, those who argue for [an eta value] as high as 2 should be advocating very strong redistribution policies." (p 204)

In conclusion (p 204): "Given the centrality of risk, scientific advance, and ethics, in our view, the question should really be why, with some important exemptions, did the previous literature pay inadequate attention to these issues?

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[27] It is interesting that in the economics of climate change Stern as well as his critics (and many others) seek a firm foundation in neoclassical economic theory, notably Ramsey (1928) who "developed the standard social welfare discounting formula $r = \eta g + \rho$, where r is the consumption discount rate, $\eta$ is the elasticity of the social benefits attained (also called the social marginal utility), g is per-capita consumption growth rate, and $\rho$ is the time discount rate (also called the pure rate of time preference). The equation arises from comparing the social value of a bit of consumption in the future with a unit now and asking how it falls over time, the definition of a discount rate." (Stern and Taylor 2007, p 203)

Ramsey was a mathematical genius who died in 1930 at 26, a protégé of Keynes who according to Wikipedia said: "The article is terribly difficult reading for an economist, but it is not difficult to appreciate how scientific and aesthetic qualities are combined in it together." Keynes's admission is reassuring to know for lesser economists including this writer! It reinstates a human dimension which often seems to be remote from macroeconomics.

Neoclassical economics has come under attack partly as a result of the Stern *Review* itself and partly because of the apparent failure of orthodox economists to anticipate the current global financial crisis. Appendix 5 discusses how a new economic paradigm may be coming into focus.

There was much structural caution in our approach. We left out many risks that are likely to be important, for example, the possibility of strong disruption of carbon cycles by changes to oceans and forests. It is possible that risks and damages are higher than we estimated. But one thing is clear: however unpleasant the damages from climate change are likely to appear in the future, any disregard for the future, simply because it is in the future, will suppress action to address climate change."

***A Stern action scenario, in his own words***

There is still time to avoid the worst impacts of climate change, if we take strong action now.

This *Review* has assessed a wide range of evidence on the impacts of climate change and on the economic costs, and has used a number of different techniques to assess costs and risks. From all of these perspectives, the evidence gathered by the Review leads to a simple conclusion: the benefits of strong and early action far outweigh the economic costs of not acting.

In contrast, the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year.

So prompt and strong action is clearly warranted. Because climate change is a global problem, the response to it must be international. It must be based on a shared vision of long-term goals and agreement on frameworks that will accelerate action over the next decade, and it must build on mutually reinforcing approaches at national, regional and international level.

Adaptation to climate change – that is, taking steps to build resilience and minimize costs – is essential. It is no longer possible to prevent the climate change that will take place over the next two to three decades, but it is still possible to protect our societies and economies from its impacts to some extent – for example, by providing better information, improved planning and more climate-resilient crops and infrastructure. Adaptation will cost tens of billions of dollars a year in developing countries alone, and will put still further pressure on already scarce resources. Adaptation efforts, particularly in developing countries, should be accelerated.

The costs of stabilizing the climate are significant but manageable; delay would be dangerous and much more costly.

The risks of the worst impacts of climate change can be substantially reduced if greenhouse gas levels in the atmosphere can be stabilized between 450 and 550 ppm $CO_2$ equivalent ($CO_2$e). The current level is 430 ppm $CO_2$e today, and it is rising at more than 2 ppm each year. Stabilization in this range would require emissions to be at least 25% below current levels by 2050, and perhaps much more.

Ultimately, stabilization – at whatever level – requires that annual emissions be brought down to more than 80% below current levels. This is a major challenge, but sustained long-term action can achieve it at costs that are low in comparison to the risks of inaction. Central estimates of the annual costs of achieving stabilization between 500 and 550 ppm $CO_2$e are around 1% of global GDP, if we start to take strong action now.

Costs could be even lower than that if there are major gains in efficiency, or if the strong co-benefits, for example from reduced air pollution, are measured. Costs will be higher if innovation in low-carbon technologies is slower than expected, or if policy-makers fail to make the most of economic instruments that allow emissions to be reduced whenever, wherever and however it is cheapest to do so.

It would already be very difficult and costly to aim to stabilize at 450 ppm $CO_2e$. If we delay, the opportunity to stabilize at 500-550 ppm $CO_2e$ may slip away.

Action on climate change is required across all countries, and it need not cap the aspirations for growth of rich or poor countries.

The costs of taking action are not evenly distributed across sectors or around the world. Even if the rich world takes on responsibility for absolute cuts in emissions of 60-80% by 2050, developing countries must take significant action too. But developing countries should not be required to bear the full costs of this action alone, and they will not have to. Carbon markets in rich countries are already beginning to deliver flows of finance to support low-carbon development, including through the Clean Development Mechanism.[28] A transformation of these flows is now required to support action on the scale required.

Action on climate change will also create significant business opportunities, as new markets are created in low-carbon energy technologies and other low-carbon goods and services. These markets could grow to be worth hundreds of billions of dollars each year, and employment in these sectors will expand accordingly. Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries.

A range of options exists to cut emissions; strong, deliberate policy action is required to motivate their take-up.

Emissions can be cut through increased energy efficiency, changes in demand, and through adoption of clean power, heat and transport technologies. The power sector around the world would need to be at least 60% decarbonized by 2050 for atmospheric concentrations to stabilize at or below 550ppm $CO_2e$, and deep emissions cuts will also be required in the transport sector.

Even with very strong expansion of the use of renewable energy and other low carbon energy sources, fossil fuels could still make up over half of global energy supply in 2050. Coal will continue to be important in the energy mix around the world, including in fast-growing economies. Extensive carbon capture and storage will be necessary to allow the continued use of fossil fuels without damage to the atmosphere.

Cuts in non-energy emissions, such as those resulting from deforestation and from agricultural and industrial processes, are also essential.

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[28] The CDM allows emission-reduction (or emission removal) projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one ton of $CO_2$. These CERs can be traded and sold, and used by industrialized countries to a meet part of their emission reduction targets under the Kyoto Protocol. The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in how they meet their emission reduction limitation targets (http://cdm.unfccc.int/about/index.html).

With strong, deliberate policy choices, it is possible to reduce emissions in both developed and developing economies on the scale necessary for stabilization in the required range while continuing to grow.

Climate change is the greatest market failure the world has ever seen, and it interacts with other market imperfections. Three elements of policy are required for an effective global response. The first is the pricing of carbon, implemented through tax, trading or regulation. The second is policy to support innovation and the deployment of low-carbon technologies. And the third is action to remove barriers to energy efficiency, and to inform, educate and persuade individuals about what they can do to respond to climate change.

Climate change demands an international response, based on a shared understanding of long-term goals and agreement on frameworks for action. Many countries and regions are taking action already: the EU, California and China are among those with the most ambitious policies that will reduce greenhouse gas emissions. The UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol provide a basis for international co-operation, along with a range of partnerships and other approaches. But more ambitious action is now required around the world.

Countries facing diverse circumstances will use different approaches to make their contribution to tackling climate change. But action by individual countries is not enough. Each country, however large, is just part of the problem. It is essential to create a shared international vision of long-term goals, and to build the international frameworks that will help each country to play its part in meeting these common goals.

Key elements of future international frameworks should include:

- Emissions trading: Expanding and linking the growing number of emissions trading schemes around the world is a powerful way to promote cost-effective reductions in emissions and to bring forward action in developing countries: strong targets in rich countries could drive flows amounting to tens of billions of dollars each year to support the transition to low-carbon development paths.
- Technology cooperation: Informal co-ordination as well as formal agreements can boost the effectiveness of investments in innovation around the world. Globally, support for energy R&D should at least double, and support for the deployment of new low-carbon technologies should increase up to five-fold. International cooperation on product standards is a powerful way to boost energy efficiency.
- Action to reduce deforestation: The loss of natural forests around the world contributes more to global emissions each year than the transport sector. Curbing deforestation is a highly cost-effective way to reduce emissions; large scale international pilot programs to explore the best ways to do this could get underway very quickly.
- Adaptation: The poorest countries are most vulnerable to climate change. It is essential that climate change be fully integrated into development policy, and that rich countries honor their pledges to increase support through overseas development assistance. International funding should also support improved regional information on climate change impacts, and research into new crop varieties that will be more resilient to drought and flood.

***Failing to act***

The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response.

Climate change will affect the basic elements of life for people around the world – access to water, food production, health, and the environment. Hundreds of millions of people could suffer hunger, water shortages and coastal flooding as the world warms.

Using the results from formal economic models, the *Review* estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.

The investment that takes place in the next 10-20 years will have a profound effect on the climate in the second half of this century and in the next. Our actions now and over the coming decades could create risks of major disruption to economic and social activity, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century. And it will be difficult or impossible to reverse these changes.

Climate change could have very serious impacts on growth and development. If no action is taken to reduce emissions, the concentration of greenhouse gases in the atmosphere could reach double its pre-industrial level as early as 2035, virtually committing us to a global average temperature rise of over $2^0$C. In the longer term, there would be more than a 50% chance that the temperature rise would exceed $5^0$C. This rise would be very dangerous indeed; it is equivalent to the change in average temperatures from the last ice age to today. Such a radical change in the physical geography of the world must lead to major changes in the human geography – where people live and how they live their lives.

Even at more moderate levels of warming, all the evidence – from detailed studies of regional and sectoral impacts of changing weather patterns through to economic models of the global effects – shows that climate change will have serious impacts on world output, on human life and on the environment.

All countries will be affected. The most vulnerable – the poorest countries and populations – will suffer earliest and most, even though they have contributed least to the causes of climate change. The costs of extreme weather, including floods, droughts and storms, are already rising, in rich as well as in poor countries.

The world does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and in the structure of economies have created opportunities to decouple growth from greenhouse gas emissions. Indeed, ignoring climate change will eventually damage economic growth.

***Endnote: Stern has turned more pessimistic***

Less than 18 months after publishing his *Review*, Stern told the media in April 2008 that he should have presented a gloomier view of the future (see, for instance, Harvey and Pickard in the *Financial Times*, 2008). Before that, he had delivered the Richard T. Ely lecture to the annual meeting of the American Economic Association in January 2008 (Stern 2008).

Two key passages that were not apparently part of the main review in 2006, read:

"There seems little doubt that, under BAU, the annual increments to stocks would average somewhere well above 3 ppm $CO_2$e, perhaps 4 or more, over the next century. That is likely to take us to around, or well beyond, 750 ppm $CO_2$e by the end of the century. If we manage to stabilize there, that would give us around a 50–50 chance of a stabilization temperature increase above $5^0$C. This is a high probability of a disastrous transformation of the planet [see below].

The issue is still more worrying than that of dealing with very large damages with very low probability.

Further, we should emphasize that key positive feedback from the carbon cycle – such as release of methane from the permafrost, the collapse of the Amazon, and thus the destruction of a key carbon sink, and reduction in the absorptive capacity of the oceans – has been omitted from the projected concentration increases quoted here. It is possible that stocks could become even harder to stabilize than this description suggests." (p 5)

"We do not really know what the world would look like at $5^0$C above pre-industrial times. .. Humans (dating from around 100,000 years or so) have not experienced anything that high. Around 10,000–12,000 years ago, temperatures were around $5^0$C lower than today, and ice sheets came down to latitudes just north of London and just south of New York. As the ice melted and sea levels rose, England separated from the continent, rerouting much of the river flow. These magnitudes of temperature changes transform the planet." (p 6)

One year out from the *Review*, Stern (2008) thought it was too cautious on all four of the key structural elements: emissions growth, carbon cycle, climate sensitivity, and damages from a given temperature:

- Ross Garnaut working for the Australian Labor government on climate change is revisiting the emissions scenarios in the IPCC *Special Report on Emissions Scenarios* (Nakicenovic et al. 2000). The Stern *Review* used the second highest of the four scenarios (A2). Garnaut is suggesting that the highest of the four, A1FI, is likely to be the best description of BAU.[29] Key among the reasons is the growth rates of the developing world, particularly China and India, and their continued dependence on coal.
- The carbon cycle is likely to weaken as a result of, for example, the possible collapse of the Amazon forest at temperature increases of above 3–$4^0$C, or the decreasing absorptive capacity of the oceans. Further, a thawing of the permafrost is likely to result in strong methane release.
- The climate sensitivity assumed in the review (the expected overall temperature increase from a doubling of greenhouse gas stock) is likely to be conservative.
- The damages from given temperature increases assumed in the Stern *Review* seem very low. The *Review*'s mean damage loss (based on estimates in the economic literature)

[29] Many scientists do likewise. Strictly speaking, it is against the philosophy of scenario planning as practiced by the IPCC and adopted in this report.

from $5^0C$ was around 5% of GDP. A temperature increase of $5^0C$ would most likely result in massive movements of population and large-scale conflict.

"Considering these structural factors together, the modeling of the Stern *Review* probably underestimated significantly the risks of high damages from BAU, perhaps by 50 percent or more." (p 22)

The reason for Stern changing his mind in 2007-08 was at least partly the publication of IPCC (2007), which predicted a temperature rise of $3^0C$ or more within the next 100 years, unless greenhouse gas emissions were stabilized and then cut within the next decade.

But he defended his estimates of the cost of taking action on emissions, which he put in the report at about 1% of global GDP. "Subsequent reports, [from] McKinsey, the International Energy Agency, the Intergovernmental Panel on Climate Change, have pointed to the [Stern *Review*'s] costs of action being roughly in the right ball park. Nothing [since] has led me to revise the cost of action," he said (Harvey and Pickard 2008).

In 2009, he reinforced and updated the message of the 2006 *Review* in *Blueprint for a Safer Planet* (Stern 2009). In it, he has strengthened his position compared with the *Review*, based partly on Jim Hansen's argument that the emissions target should be no larger than 350 ppm $CO_2$ (400 ppm $CO_2e$), and to scientific concerns about the possibility of tipping points such as the collapse of ice sheets, the dying of the Amazon forest, or the release of methane from the permafrost, which could lead to an accelerated process of climate change:

"These scientific arguments are very powerful in terms of bringing home the magnitudes of the risks. They convince me that 500 ppm $CO_2e$, with its high probability of exceeding $2^OC$ above pre-industrial levels (96%) and a 44% probability of being above $3^OC$ would indeed be a risky place to be." (p 150) He continues, however: "The problem .. is that we are already at .. around 380 ppm $CO_2$ and we are adding about 2.5 ppm per annum. We are unlikely to turn these additions into negative numbers for a very long time. We will surely be at [~400 ppm $CO_2$] within ten years. To push hard for a lower target could disrupt the possibility of agreement in the very near future .. we risk appearing to ask for the impossible." (p 150)

## THE GARNAUT REPORT

### *Background*

The eight governments of Australia's states and territories in April 2007 asked economics professor and past Australian ambassador to China Ross Garnaut to report on the likely effect of human-induced climate change on Australia's economy, environment, and water resources in the absence of effective national and international efforts to substantially cut greenhouse gas emissions. Other parts of the terms of reference included reporting on the possible ameliorating effects of international policy reform on climate change, the costs and benefits of various international and Australian policy interventions on Australian economic activity, and Australia's role in the development and implementation of effective international climate change policies.

At the time, all eight state and territory governments were Labor, while the federal government since 1996 had been a conservative coalition headed by John Howard. In

November 2007, a Labor government took over headed by Kevin Rudd. One of the first actions of that government was to ratify the Kyoto Protocol, leaving the United States as the only major nation who had not yet done so.

The final 600-page Garnaut Review was published in September 2008 (Garnaut 2008a). The decision-making framework of the report, and its views on the limitations of economic modeling relative to what is important to take into account, is reported below.

Subsequent sections attempt to encapsulate two scenarios, based largely on the last chapter, 24, of the review. The concluding section alludes to the Australian Government's White Paper on a carbon pollution reduction scheme in December 2008, and to Professor Garnaut's reaction to the white paper (Garnaut 2008b). The descriptions concentrate on the international aspects of the investigation.

***A decision-making framework***

The central policy issue is: *What extent of global mitigation, with Australia playing its proportionate part, provides the greatest excess of gains from reduced risks of climate change over costs of mitigation*?

The mitigation *costs* are experienced through conventional economic processes and can be measured through formal economic modeling, but only some of the *benefits* of mitigation are experienced through conventional market processes and are therefore amenable to economic modeling.

The challenge is to make sure that important effects are brought to account even if they cannot be measured. The long time frames involved create a special challenge, requiring us to measure how we value the welfare of future generations relative to our own.

The questions are extraordinarily complex. The answers depend on our judgments about the prospects for effective international mitigation, on the efficiency of measures to achieve reductions in greenhouse gas emissions, including supporting measures that affect the market response to the mitigation regime, and therefore the costs of achieving various levels of abatement. They depend on the efficiency of supporting measures to share the costs of mitigation within a nation, and on the international distribution of the mitigation burden. They depend on the options for and costs of adaptation.

These decisions need to be taken under conditions of *risk* and *uncertainty*, where risk relates to events where the outcome can be placed on a known probability distribution (like the tossing of a coin). There is uncertainty when an event is of a kind that has no close precedents, or too few for a probability distribution of outcomes to be defined, or where an event is too far from better-understood events for related experience to be helpful in foreseeing possible outcomes.

Garnaut defines four types of benefits from mitigation:

1. The first type of benefit from mitigation comprises currently measurable market impacts of climate change, which are avoided by mitigation. The measurement can be brought together through a computable general equilibrium economic model.

2. The second type comprises market impacts similar in nature to the first, but not yet measured. They are, in principle, amenable to quantitative analysis. Examples include the impact of climate change on the tourism industry. As with the first type of benefit, the estimation of these effects would be in monetary values of GDP or consumption.
3. The third type of benefit of mitigation is the insurance value that it provides. Humans tend to be risk-averse when the outcomes include the possibility of large loss. In such cases, mitigation has additional insurance value. What would we be prepared to pay to avoid a small probability of a highly damaging or possibly catastrophic outcome? Uncertainty strongly plays into this category of benefits, as the probability of extreme or catastrophic climate impacts is not known from experience, and must instead be based on expert judgment. The possibility of outcomes that most people would consider to be catastrophic makes this a particularly important element of the assessment.
4. The fourth type of benefit – non-market impacts – is more difficult to conceptualize, and quantify. The focus of policy making is on maximizing the welfare (utility) of a nation's inhabitants. We can think of a utility function as rising with Australian consumption of goods and services, and also with a number of non-monetary services, for example the valuation of environmental amenity. They include the value placed on the integrity of coral reefs and other features of the Australian and international landscapes, on known shorelines, on genetic diversity and on the survival of species. They also include the value that Australians place on long-established communities and social structures built around particular patterns of climate, or the use of green urban gardens and playing fields for recreation.

   To include such elements in a national utility function is not to place intrinsic value on environmental conservation, as some argued that the Garnaut Review should have done. We only have to accept that many people value such things both for themselves and as options for their offspring and future generations, and would be prepared to sacrifice some consumption of goods and services to retain them. People also value the avoidance of poverty and trauma in other countries, as demonstrated in their continued support of public and private international development assistance and disaster relief.

Other important aspects of the framework are briefly listed below.

**How effective adaptation reduces the cost of climate change**

Some costs of climate change can be reduced by the adaptive behavior of individuals and firms, and by policies that support productive adaptation. This requires a strong applied science base; good markets for reallocation of resources, goods and services; and capital for investment in defensive structures and new productive capacity that is more suitable to the new environment.

All of these capacities are more abundant in developed than in low-income developing countries. For the latter, the impact of climate change is likely to be undiluted and more severe.

The costs of adaptive responses will generally come early, and the benefits from reduced costs of climate change later.

Some of the most important adaptive responses to climate change, and the most difficult to bring to account in an analysis of optimal levels of mitigation, involve changes in attitudes and values. The city dwellers of densely populated regions of Northeast Asia have long been accustomed to life that is almost entirely separated from the natural environment.

**Measuring the benefits of mitigation against the costs**

The benefit from mitigation is the cost of climate change avoided, after the costs and ameliorating effects of adaptation had been taken into account. The costs of mitigation come earlier and are more certain. The benefits come later and are less certain. How do we compare later with earlier benefits? How do we compare more with less certain outcomes?

The costs and benefits of mitigation fall on and accrue to different groups in the community, and are felt and valued in various ways by different people. How do we weigh the relative effects on welfare of different people? In particular, what relative weight do we give to costs and benefits to the rich and to the poor? An overall assessment of whether mitigation is worthwhile may depend on the distribution of costs and benefits across the community.

The relevant mitigation is global. A single country's action is relevant only in its direct and indirect contribution to global mitigation. The benefits depend overwhelmingly on what other countries are doing.

**Valuing the future relative to the present**

Garnaut comes to a similar though not identical conclusion as Stern based on the two main elements of utility theory. He also favors a near-zero pure rate of time preference, giving nearly identical weights to current and future generations.

The second element in the discount rate is the measure of society's concern for equity in income distribution – the marginal elasticity of utility with respect to consumption. We accept that a dollar of incremental income means less to the utility of the rich than of the poor. The people of tomorrow will have higher material incomes and wealth than people today, although this is likely to be offset because climate change may greatly diminish the availability of non-market services for future generations.[30] As a result, one cannot be sure that, despite much higher material consumption, the average utility of people in future will be greater than the average utility today. Hence, linking the marginal elasticity of utility to the growth in per capita income may lead to higher than intended discount rates. Furthermore, if considerable weight is given to the bad end of the probability distribution of outcomes from climate change, there is a possibility that utility may be lower for many people in future than at present.

In conclusion, the discount rate resulting from the above considerations may be positive – Garnaut suggests somewhere between 1.35% and 2.65% for Australia – but it is likely to fall short of the discount rate at which investors choose to allocate capital between permits and

[30] Even with the qualification in the second half of the sentence, the basic view seems to be that economic growth will not be significantly affected even by large global and regional temperature increases. But Garnaut says himself that if things go badly, they could go very badly. If the bad end of the probability distribution gets more weight, as may happen in his implicit "BAU" scenario summarized below, the utility may be lower, not higher – people may not become significantly richer and income distributions may crowd towards the lower end. Furthermore, even the perception of an increased future threat might shift the utility function downwards.

other financial investments over time (assumed to be about 4% in real terms including allowance for risk).

***Fateful decisions – the brighter view***

*Garnaut saw 2009, leading up to the Copenhagen climate change meeting in December, as a crucial year. The main scenario assumes that things develop reasonably well but there is sufficient doubt in his mind to suggest a worst case, reported in the next section. The main 'Garnaut scenario' is based on Chapters 24 and 9 of his review and uses his own words, slightly rearranged and lightly edited.*

There are times in the history of humanity when fateful decisions are made. The decision this year and next on whether to enter a comprehensive global agreement for strong action on climate change is one of them.

Or rather, in this case, a fateful series of decisions. The world will not arrive at a satisfactory single settlement in one meeting in Copenhagen, or in one meeting after that.

If things go well, the decisions of many governments will lead into a comprehensive global agreement in Copenhagen. That agreement will lead to the world taking major new steps on mitigation in all major countries. Substantial financial flows to developing countries for mitigation and adaptation will expand beyond recognition. Structures and incentives will have been established to support a large increase in investment in the new technologies necessary for mitigation to occur at reasonable cost.

If things go well, very well, Copenhagen will be the end of one process, and the beginning of others that will lead, over time, to effective global mitigation at a level that reduces risks of dangerous kind to an extent that seems acceptable to most informed people.

The analysis of the current international situation in the Garnaut Review tells us that a good outcome is not assured. The international community is on a course plotted before the implications of the current era of growth had been absorbed into its decision-making framework. It is on a course plotted before humanity had absorbed the implications of the acceleration of economic growth in the early 21st century; the concentration of that growth in economies at the stage of development when growth absorbs huge amounts of energy; and in countries where coal is the cheapest and most convenient energy source. New knowledge changes the calculus.

Success at Copenhagen is not an agreement along the lines of the Bali Roadmap of December 2007. Success will need to build on the foundations of Bali and earlier UNFCCC agreements, because there is no time to start again. But the content of any agreement will need to go beyond what had been contemplated at Kyoto and Bali.

Success at Copenhagen requires agreement to large emissions reductions from developed countries, plus agreement on a framework for early contributions to mitigation from China and as soon as possible from other successful developing countries.

This formulation underplays the importance of another part of the contemporary reality. It is much more likely that effective mitigation from developed countries will be achieved within a comprehensive global mitigation regime. Participation by developing countries would remove competitive distortion in trade-exposed industries.

It would demonstrate to the developed countries that their contributions are not pointless self-sacrifice, but part of a solution to the global problem of climate change. So success at Copenhagen, or at subsequent meetings convened for the purpose, must encompass inclusion of developing countries in a global mitigation regime. The participation of China is urgent, and comprehensive participation, beyond China, is necessary for the political and economic viability of the regime.

So the fateful decision at Copenhagen is not just about whether there will be a comprehensive regime. It has to be a credible agreement. This means that the sum of national commitments must “add up” to the environmental objective.

Only a comprehensive international agreement can provide the wide country coverage and motivate the coordinated deep action that effective abatement requires. The only realistic chance of achieving the depth, speed and breadth of action now required from all major emitters is allocation of internationally tradable emissions rights across countries. For practical reasons, allocations across countries will need to move gradually towards a population basis.

An initial agreement on a global emissions path towards stabilization of the concentration of greenhouse gases at 550 $CO_2e$ is feasible. 450 $CO_2e$ is a desirable next step. Agreement on such an agreement would build confidence for the achievement of more ambitious stabilization objectives.[31]

All developed high-income countries, and China, need to be subject to binding emissions limits from the beginning of the new commitment period in 2013. Other developing countries – but not the least developed – should be required to accept one-sided targets below . For these countries, acceptance of constraints would not be binding, but there would be large advantages for them in participating.

The trajectories for emissions constraint, based on modified contraction and convergence, would provide opportunities for them to do better, and to sell surplus permits, providing new economic opportunities. Acceptance of constraints would allow developing countries access to the low-emissions technology and adaptation funding commitments of the developed countries. They would avoid the disruption to trade that might come to be associated with standing aside from international cooperation on mitigation.

We must be clear about the gap between where we are and where we need to be. There are few countries in which mitigation policies have yet had a substantial effect on emissions reduction. Global expenditure on low-emissions technologies has been at a low ebb – much lower than had been induced by the high oil prices of the 1970s. No developed country has

[31] The Copenhagen Accord, which was the only “formal” result of the Copenhagen COP-15 meeting in December 2009, for the first time agreed to work toward a maximum global temperature of at most $2^{O}C$ above the pre-industrial level, which is compatible with reducing atmospheric $CO_2$ to 350 ppm, a much more ambitious target than assumed by Stern, Garnaut, and others writing in 2006-08. While the Accord was not formally adopted, 109 countries by March 2010 had submitted emissions policies and targets for 2020, which is regarded as indicative of a positive desire of most participating countries to maintain momentum towards formal international agreement by, say, 2011. The end of Appendix 5 has further detail on events since the global economic crisis hit in October 2008, including the failure to pass formal emissions trading legislation in the US and Australia in 2009, and some possible consequences of this.

yet put in place policies that can be reasonably expected to achieve its share of the reductions in emissions necessary for 550 ppm objectives, let alone something more ambitious. While China and some other developing countries have implemented policies that are moderating the growth in emissions, no developing country has been willing to concede that binding emissions constraints should also apply to its own economy.[32]

The first essential step at Copenhagen is a comprehensive global agreement that adds up to the environmental objective to which it is directed.

Achievement of a comprehensive agreement around a 550 ppm objective would be a step forward of historic dimension. Such an achievement and its effective implementation would avoid the worst outcomes from unmitigated climate change.

It would give confidence to the international community that cooperation is possible in this difficult sphere. Once in effect, alongside a low-emissions technology commitment, it would unleash forces for innovation and structural change that would demonstrate that strong mitigation was consistent with continued economic growth, and bring more ambitious goals into the realm of the possible. It would bring the next step to 450 closer to reach.

Effective comprehensive global agreement around a 450 ppm objective, if it were realistic in conception and implementation, would be better still, for Australia and for the international community. It would be 450 ppm with overshooting, because we are already at around 450 ppm and this level will go much higher before the momentum of emissions growth is slowed, halted and then turned around.

### *If things go badly*

*The following excerpts are from Chapter 24 of the Garnaut Review (pp 592-595, and p 598).*

If things go badly, they could go very badly. When human society receives a large shock to its established patterns of life, the outcome is unpredictable in detail but generally problematic. Things fall apart.

The initial financial shocks that hit Australia in the 1890s, central Europe and the industrial world in the 1930s, or Indonesia in the 1990s, were in themselves substantial, but turned out to be small in comparison to the chain of events that followed. In themselves, these shocks could have been expected to cause a pause in growth, but not one that would throw history from its course. But each shock was large enough to exceed some threshold of society's capacity to cope with change. In each case, what might have been a recession of substantial but ordinary magnitude became a great depression. Total output fell by a fifth or more.

The associated social convulsions changed political institutions fundamentally and as permanently as human institutions can be changed. They shifted the whole trajectory of economic growth.

Unmitigated climate change, or mitigation too weak to avoid dangerous climate change, could give human society such a shock.

[32] China, however, is developing a massive "cleantech" program (in response to what it considers environmental necessity) which may be inserting new dynamics into international climate policy. See Appendix 6, section on technologies and technology policy.

The case for strong mitigation is a conservative one. Even at the levels of mitigation that now seem to be the best possible, the challenges could be considerable. In the absence of mitigation, we can be reasonably sure that they would be bad beyond normal experience.

We know that immense shocks unsettle basic institutions, with unfathomable consequences. We know that the possibilities from climate change include shocks far more severe than others in the past that have exceeded society's capacity to cope, and moved societies to the point of fracture. Here we are talking about global fracture.

If sea-level rises by a meter or more this century and as much again in the first half of the next, and displaces from their homes the people of the low-lying coasts and river banks of the island of New Guinea, it will not be a problem for Papua New Guinea and Indonesia alone.

If sea-level rises and displaces from their homes a substantial proportion of the people of Bangladesh and West Bengal, and many in the great cities of Dhaka, Kolkata, Shanghai, Guangzhou, Ningbo, Bangkok, Jakarta, Manila, Ho Chi Minh City, Karachi and Mumbai, it will not be a problem for Bangladesh, India, Pakistan, China, Thailand, Indonesia, the Philippines and Vietnam alone.

If changes in monsoon patterns and the flows of the great rivers from the Tibetan plateau disrupt agriculture among the immense concentrations of people that have grown around the reliability of water flows since the beginning of civilization, it will not just be a problem for the people of India, Bangladesh, Pakistan, Vietnam, Myanmar and China.

The problems of unmitigated climate change will be for all humanity.

During the discussions following the release of the Review's draft report in early July 2008, some critics said that my descriptions of impacts had been 'alarmist'. I responded that I was simply telling the story as it fell out of the analysis, when the emissions growth suggested by the Review's own work was applied to 'centre of the road' scientific judgments on the relationship between $CO_2$ concentrations and temperatures.

I was talking then about impacts in the middle of the probability distributions that come, as best we can judge, from contemporary science. I did not then talk about some of the possible shocks that I am discussing now: shocks that until recently were a fair way along the "possible but not very likely" end of the probability distribution, but have been moved closer to the centre by the Review's work on scenarios. Some shocks that would be severe and damaging that were once near the edges of the distributions are now near the middle. In the absence of mitigation, as we move beyond this century, some of these shocks move to the higher probability ends of the distributions. Without strong mitigation, the melting of the Greenland ice sheet, sooner or later, becomes something close to a sure thing.

There is a chance that they are wrong. Just a chance. But to heed instead the views of the minority of genuine skeptics in the relevant scientific communities would be to hide from reality. It would be imprudent beyond the normal limits of human irrationality.

It is prudent to give the major weight to the mainstream science. This is fully compatible with investing more in improvement of knowledge to narrow the dispersion of the probability distributions. The improvement of knowledge, the narrowing of uncertainty, the sharpening of predictions: all these can and should proceed alongside the commencement of international collective action in pursuit of strong mitigation.

The annual costs of strong mitigation continue to increase over the first half of the century. The mitigation process can be cut short, with due notice to those who have committed their capital to a new economy of low emissions, if at any time the international community comes to the view that new scientific knowledge establishes that the concerns of 2008 were erroneous to the extent that mitigation judgments based on them have become obsolete. Mitigation could come to a stop in 2020, for example, on the basis of new knowledge that it was unnecessary, after mitigation had been put in place to return to concentrations of 450 ppm.

In this case, Australia would have paid 2% of GNP as insurance against what would otherwise have been a high risk of immense damage. It would be a high price, but one that was reasonable on the basis of the evidence available at the time when decisions had to be made.

The consequences of inaction now are not similarly reversible. The arithmetic of Chapter 3 [with China emerging as the world's largest emitter and other developing countries also becoming major contributors to global emissions] about the new patterns of global growth takes away the time we may once have thought we had for experiment, talk, and leisurely decision making. It tells us that business-as-usual is taking us quickly towards what the science tells us are high risks of highly disruptive climate change.

So fateful decisions are to be taken at Copenhagen.

The old calculus said that there was time for all developed countries to take the early steps in mitigation, and then for all developing countries to join at a later unspecified date. The old calculus said that it was good enough for the developing countries to begin to contribute through the Clean Development Mechanism and in other ways that made no additional contribution to the global mitigation effort, beyond commitments that the developed countries had already made.

The updated projections show that approaches based on the old calculus will not hold the risks of dangerous climate change to acceptable levels.

The fateful decision at Copenhagen will follow many decisions in individual countries. And after Copenhagen, there will be more big decisions to be made. If there is a comprehensive and effective global agreement, the scene will be set for reconsideration of ambition once it has been demonstrated that mitigation is consistent with continued economic growth.

If there is no such agreement, the outlook is an unhappy one. On a balance of probabilities, the failure of our generation would lead to consequences that would haunt humanity until the end of time.

### *Global economic crisis intervenes in late 2008*

Following the final Garnaut Review on 30 September, the Australian government published its White Paper on a carbon pollution reduction scheme in December 2008. Between the two dates, the global financial crisis struck. The White Paper commented (p iii):

"The world is currently confronting the worst financial crisis in three quarters of a century, but this does not mean we can ignore the threat climate change poses to our long term economic prosperity. On the contrary, this current crisis makes it more important we secure the long term prosperity that comes from building the low pollution economy of the future.

It is often easier for governments to focus on immediate circumstances at the expense of long term challenges, but ignoring these challenges only makes them worse. Analysis from the Australian Treasury and Professor Ross Garnaut demonstrates the longer we wait to take action on climate change, the more it will cost.

The Australian Government will continue to act decisively to protect Australia from the worst effects of the global financial crisis while also addressing the long term challenge of climate change.

The Government is determined to get the balance right. This means securing Australian jobs and assisting households today, while at the same time moving to the low pollution economy that will create the jobs of the future."

The White Paper set a seemingly low target for Australia unilaterally to reduce emissions by 2020, of only 5%, though it works out much higher on a per capita basis because of the country's relatively rapid population growth. In a comment, Professor Garnaut (2008b) agreed with the target in the absence of other countries following suit, but he criticized the government for setting too low a target (15%) if other countries did so:

"The white paper rules out Australia contributing to a global effort to achieve ambitious mitigation targets prior to 2020. That is a pity. There is a chance, just a chance, that with Barack Obama as president of the United States, high ambition at Copenhagen will turn out to be feasible. In the meantime, Australia cannot play a strongly positive role in encouraging the global community towards the best possible outcomes if it has ruled out in advance its own participation in strong outcomes.

This weakness of the white paper could be corrected without substantial unpicking of the policy package."

## SACHS'S MILLENNIUM VISION

Jeffrey D. Sachs is director of the Earth Institute and professor of sustainable development at Columbia University, and a special adviser to UN Secretary-General Ban Ki-moon on the millennium development goals discussed in an earlier section. His book, *Common Wealth: Economics for a crowded planet* (Sachs 2008) contains perhaps the most convincing blueprint for the more optimistic IPCC growth scenarios, including the A1B and A1T variants.[33] On the other hand, a BAU do-nothing horror scenario can also be derived, much as it could from the Stern and Garnaut Reviews. As Edward O. Wilson writes in the foreword to the book (p xii): "As the large mass of data summarized in *Common Wealth* shows with sobering clarity, we have arrived at a narrow window of opportunity. .. Please look at the

[33] It is difficult, however, to see how the fossil fuel intensive scenario, A1FI, could fit comfortably with the millennium goals, though Sachs does advocate carbon sequestration and storage (CCS) based on IPCC's background study on the subject (Metz et al. 2005).

numbers, then, in *Common Wealth.* Extrapolate a bit. We can still correct the course, but we do not have much time left to do it."

### *Common challenges, common wealth*

The first chapter in Sachs's book provides a global situation report based on "the defining challenge of the 21st century" – which will be to face the reality that humanity shares a common fate on a crowded planet. The world can certainly save itself, he says, but only if we recognize accurately the dangers that humanity confronts together. "The world's current ecological, demographic, and economic trajectory is unsustainable, meaning that if we continue with "business-as-usual", we will hit social and ecological crises with calamitous results." (p 5). He identified four causes of potential crises – "problems that will not solve themselves" (p 6):

1. Human pressures on the Earth's ecosystems and climate, unless mitigated substantially, will cause dangerous climate change, massive species extinctions, and he destruction of vital life-support functions.
2. The world's population continues to rise at a dangerously rapid pace, especially in the regions least able to absorb a rising population.
3. One sixth of the world remains trapped in extreme poverty unrelieved by global economic growth, and the poverty trap poses tragic hardships for the poor themselves and great risks for the rest of the world.
4. We are paralyzed in the very process of global problem solving, weighed down by cynicism, defeatism, and outdated institutions.

The threats can be avoided only if we cooperate effectively. Sachs proposes the following goals for the coming decades, each corresponding to a critical problem above (pp 6-7):

1. Sustainable systems of energy, land, and resource use that avert the most dangerous trends of climate change, species extinction, and destruction of ecosystems.
2. Stabilization of the world population at eight billion or below by 2050 through a voluntary reduction of fertility rates.
3. The end of extreme poverty by 2025 and improved economic security within the rich countries as well.
4. A new approach to global problem solving based on cooperation among nations and the dynamism and creativity of the nongovernmental sector.

### *A blueprint for meeting the millennium promises*

The best-case 'Sachs scenario' is based on Chapter 13 of Sachs (2008): 'Achieving global goals'.

The millennium promises are the world's goals for sustainable development and the guide to our common actions. Accomplishing these goals requires a complex global process, beyond the capacity of governments alone or any other single sector of society. The process will involve many actors:

- The first essential process is the mobilization of science around the issue.
- The second step is entrepreneurship: incentives to push businesses, innovators and social entrepreneurs to come up with practical solutions.
- The third step is scaling up – taking proven solutions and applying them globally.

Global problem-solving requires a complex interplay of the public, private, and not-for-profit sectors:

- The four core responsibilities of the *public sector* are to fund basic science, promote early stage technologies, create a global framework for solutions, and finance the scale-up of successful innovations and technologies.
- The responsibilities of the *private profit-making sector* are to invest in R&D (often with public funding) and to implement large-scale technological solutions in partnership with the public sector.
- *The not-for-profit sector* has five key roles: public advocacy, social entrepreneurship and problem-solving, seed funding of solutions, monitoring the accountability of government and the private sector, and scientific research, notably in academic institutions.

For each millennium goal, such as dealing with desertification, anthropogenic climate change, excessive fertility rates or extreme poverty, there is a lengthy process from the time when the problem is perceived by experts (who are typically trained scientists), often a decade or more ahead of public opinion. As time progresses, three things come into sharper view: First, the problem becomes much clearer, possibly because of a public disaster such as Hurricane Katrina. Secondly, the failure of the early steps or market forces alone becomes widely evident, leading to growing calls for stronger public actions. Thirdly, field trials and pilot projects gives stronger guidance to what can work at a large scale.

The next step is a global agreement for real action rather than merely a framework for recognizing the problem – the tipping point has arrived, as happened in the past with ozone depletion, HIV/AIDS and malaria control, and the fight against extreme poverty. Global treaties or protocols are agreed on, funding mechanisms put in place for the scale-up, and innovative economic frameworks (global funds, permit systems, new global standards) are adopted to guide the actions of governments and the private sector.

Success is achieved by constant feedback as actions and results are compared with targets and time lines, as for the Millennium Goals. The best-case scenario, by definition, is one where many goals are pursued in these frameworks, and their hierarchies and the interactions between them are built into the process.

Global funds point the way for success across the broad range of challenges. The aim is to simplify the global aid architecture and make it more transparent, science-based, and responsive to the level of actual needs. *Seven global funds* – expanded from current versions – would cover the vast range of sustainable development needs:

1. A fund to fight AIDS, tuberculosis, malaria and other diseases
2. A fund to achieve an African green revolution

3. An environment facility dramatically expanding in scale the existing fund jointly managed by the UN Development Program, the UN Environment Program, and the World Bank
4. A population fund greatly expanded to ensure universal access to sexual and reproductive health services by 2015, and the focal point for the effort to stabilize the global population below eight billion by 2050
5. An infrastructure fund
6. An education fund
7. A community development fund to support community-based development efforts that cut across sector programs such as health, education, infrastructure or population.

Funding has also come from private foundations such as the Rockefeller Foundation and more recently the Gates foundation. But even with their vast resources, the global needs across poverty, disease, climate, energy systems and population will be beyond the means of any private foundation. The real work of great foundations lies elsewhere, in spearheading the search for solutions, notably in the field of basic science and technology.

One of the greatest unmet challenges is to find a mechanism to support basic scientific research where the targets of the research are for global needs, rather than national economic advantage or private profits. There is no easy fix to this problem, which spans the needs to fund R&D across the spectrum of disease control, agriculture, climate change, sustainable energy, water-management technologies, and biodiversity monitoring and conservation. The Sachs scenario has an international R&D committee in each area of concern to make recommendations on the allocation of research funds, and the active involvement of private and public organizations such as the World Health Organization, the Food and Agriculture Organization, and the UN Environment and Development Programs take the lead in cooperation with the Gates and Rockefeller and other private organizations.

Innovations by nongovernmental organizations are an important element of this scenario. Ideas, which are the key to global solutions, start with individual entrepreneurs. NGOs have repeatedly played a pivotal role in identifying local needs, proving new technologies, and identifying novel implementation strategies. The Grameen Bank pioneered by Muhammad Yunus in Bangladesh to provide microcredit to women, an idea since spreading to many countries, is cited as an outstanding example. Microcredit is now a widely used tool internationally in the fight against global poverty, assisted by the Grameen Foundation which was formed to expand Muhammad Yunus's concept beyond Bangladesh to "combine the power of microfinance, technology and innovative solutions to defeat global poverty" in Sub-Saharan Africa, Asia, the Arab World, and the Americas.[34]

Modern information and communications technology has been important in revolutionizing every aspect of development practice, and will enable more and more countries and isolated regions within countries to join the convergence club.

[34] http://www.grameenfoundation.org/. See further Appendix 6 on technology, in particular the section (towards the end) on implications for the world's least developed societies

Sachs specifies how to meet the millennium challenges of environmental degradation and climate change, population change, extreme poverty, and achieving the millennium goals (p 309) and estimates the financial needs of the program to be about 2.4% of donor countries' GDP (p 310).

***Consequences of "business-as-usual"***

The table on page 309 in Sachs (2008) mentioned above has two additional columns: 'Business-as-usual' and 'The costs of failure'. The consequences of not meeting the four challenges are:

1. **Environmental degradation**. *Business-as-usual*: Climate change moves in excess of dangerous thresholds, massive species extinction, growing water stress. *Costs of failure*: Massive dislocations and deaths due to crop failures, famine, and failures of critical ecosystems.

2. **Population change**. Business-as-usual: Population rising to more than 9 billion, and possibly more than 10 billion. *Costs of failure*: Massive youth bulge, environmental pressures, and unchecked global migration.

3. **Extreme poverty**. *Business-as-usual*: 1 billion people stuck in the poverty trap. *Costs of failure*: A world of instability, failed states, and uncontrolled pandemic diseases.

4. **Breakdown of global problem solving**: *Business-as-usual*: Growing tensions combined with the failure of global goals. *Costs of failure*: Greatly increased risk of global conflict, provoked by growing sources of economic, demographic, environmental, and social instability.

## THE THREAT MARGIN TIGHTENS TO 350 PPM $CO_2$ OR LESS

During 2009, a notable consensus was developing among scientists that a 450 ppm $CO_2$ stabilization rate was unduly risky, and that any safe increase in global warming must be kept below $2^{O}C$. Humanity should aim at reducing emissions to 350 ppm $CO_2$ (or about 400 ppm $CO_2e$).

This was triggered to a considerable extent by new scientific findings, but NASA's James Hansen was the first to articulate the increasing risks, going back decades. A selection of his extensive writings is discussed immediately below, followed a series of other contributions.

The first of these is *Climate Code Red* (Spratt and Sutton 2008), which joins the "350 club" with the statement that arctic sea-ice loss is at the root of the problem. The authors estimate that to reverse this requires atmospheric $CO_2$ to be lowered to 300-325 ppm.

These contributions refer to climate change generally, except the last one. Since the massive bleaching events in 1998, coral reefs became known as the original "global canary" indicating the risks inherent in climate change. It is appropriate to end this appendix with a special look at the significance of coral reefs in ecosystems and the special risks they face, especially since ocean acidification has been identified as a potentially even more serious problem than the warming itself. It is based on a *Marine Pollution Bulletin* paper which specifically addresses the significance of coral reefs in ecosystems and the special risks they face (Veron et al. 2009).

## JAMES HANSEN

James Hansen, director of NASA's Goddard Institute for Space Studies and widely regarded as the world's foremost climatologist, provides the material for the discussion below – leading to the next heading showing a number of additional investigations inspired by Hansen's thinking that the level of atmospheric $CO_2$ should be reduced to 350 ppm or less. Hansen has been warning the world, specifically the US Congress, against the risks of climate change since at least 1988 and keeps doing so. His findings are essential in any assessment of where the global climate is heading, and whether prospects have been worsening.[35]

Mark Bowen (2008) tells how the Bush administration tried to prevent Hansen from making public statements about climate change between 2004 and 2007. The story, however, goes back much further.

### *On early recognition of climate change*

In June 1988, he presented three main conclusions to the United States Senate (Hansen 1988). (a) Global temperatures are the highest in the period of instrumental records: the four warmest years in the past century have all occurred in the 1980s. (b) The global warming is now sufficiently large that we can ascribe with a high degree of confidence a cause-and-effect relationship to the greenhouse effect. (c) Computer simulations show that the greenhouse effect is already large enough to begin to affect the probability that extreme events such as summer heat waves will occur more frequently.

Bowen (2008, p 1) notes that the policy makers seemed to get the message with 32 climate-related bills being introduced by the end of 1988. In retrospect, however, none of the bills went anywhere, and the prospects for an effective policy response looked dim. Eventually, in 2001, climate change was put on the back burner with President Bush abandoning a campaign promise to regulate carbon dioxide from coal-burning power plants, and then pulling the United States out of the Kyoto Protocol.

Meanwhile, Jim Hansen continued his campaign to inform policy makers and the US community. A few of his many contributions are noted below.

### *On scientific reticence*

Hansen (2007a): "I suggest that `scientific reticence', in some cases, hinders communication with the public about dangers of global warming. If I am right, it is important that policy-makers recognize the potential influence of this phenomenon. Scientific reticence may be a consequence of the scientific method. Success in science depends on objective skepticism. Caution, if not reticence, has its merits. However, in a case such as ice sheet instability and sea-level rise, there is a danger in excessive caution. We may rue reticence, if it serves to lock in future disasters."

[35] Another prominent scientist is with him all the way, asking, "Global warming: stop worrying and start panicking?" (Schellnhuber 2008). "My conclusion is that we are still left with a fair chance to hold the 2°C line, yet the race between climate dynamics and climate policy will be a close one" (p 14240) .

Hansen warns specifically about nonlinearities in the climate models – adding to the urgency of action. “An important point is that the nonlinear response could easily run out of control, because of positive feedbacks and system inertias.”

“IPCC reports may contain a reticence in the sense of being extremely careful about making attributions. This characteristic is appropriately recognized as an asset that makes the IPCC conclusions authoritative and widely accepted. It is probably a necessary characteristic, given that the IPCC document is produced as a consensus among most nations in the world and represents the views of thousands of scientists.” [36]

***On climate change and trace gases***

Hansen et al. (2007a) place much emphasis on paleoclimate, providing some alarming parallels: “Paleoclimate data show that the Earth’s climate is remarkably sensitive to global forcings. Positive feedbacks predominate. This allows the entire planet to be whipsawed between climate states. One feedback, the “albedo flip” property of ice/water provides a powerful trigger mechanism.[37] A climate forcing that “flips” the albedo of a sufficient portion of an ice sheet can spark a cataclysm. Inertia of ice sheet and ocean provides only moderate delay to ice sheet disintegration and a burst of added global warming.

Recent greenhouse gas emissions place the Earth perilously close to dramatic climate change that could run out of our control, with great dangers for humans and other creatures. Carbon dioxide is the largest human-made climate forcing, but other trace constituents are also important. Only intense simultaneous efforts to slow $CO_2$ emissions and reduce non-$CO_2$ forcings can keep climate within or near the range of the past million years. The most important of the non-$CO_2$ forcings is methane ($CH_4$), as it causes the second largest human-made greenhouse gas climate forcing and is the principal cause of increased tropospheric ozone ($O_3$), which is the third largest greenhouse gas forcing.

***On dangerous human-made interference with climate***

Hansen et al. (2007b): Identification of ‘dangerous’ effects is partly subjective, but we find evidence that added global warming of more than $1^{O}C$ above the level in 2000 has effects that may be highly disruptive. Based on two scenarios (one derived from past trends and an alternative keeping warming since 2000 to less than $1^{O}C$), we conclude that a $CO_2$ level exceeding about 450 ppm is “dangerous”, but reduction of non-$CO_2$ forcings can provide modest relief on the $CO_2$ constraint.

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[36] Scientists have lately abandoned their reticence to warn about the increased risk of dangerous climate change. The most dramatic example in early 2009 was the *synthesis report* from the climate change conference of scientists in Copenhagen in March (Richardson et al. 2009) which left absolutely no doubt about the urgency of the climate change challenge. The writing team included Nicholas Stern, Hans-Joachim Schellnhuber and Will Steffen among other notables.

[37] The albedo of an object is the extent to which it diffusely reflects light from the sun; the flip occurs when the sunlight reflected by white ice suddenly becomes absorbed when the ice melts to become the dark surface of open water. In the words of Hansen et al. (2007a, p 1948): “A salient feature of terrestrial climate change is its asymmetry. Warmings are rapid, usually followed by slower descent into colder climate. Given the symmetry of orbital forcings, the cause of rapid warming at glacial ‘terminations’ must lie in a climate feedback. Clearly, the asymmetric feedback is the albedo flip of ice and snow that occurs when they become warm enough to begin melting.”

We suggest that Arctic climate change has been driven as much by pollutants ($O_3$, its precursor $CH_4$, and soot) as by $CO_2$, offering hope that dual efforts to reduce pollutants and slow $CO_2$ growth could minimize Arctic change. Simulated recent ocean warming in the region of Atlantic hurricane formation is comparable to observations, suggesting that greenhouse gases may have contributed to a trend toward greater hurricane intensities. Increasing greenhouse gases cause significant warming in our model in submarine regions of ice shelves and shallow methane hydrates, raising concern about the potential for accelerating sea-level rise and future positive feedback from methane release. Growth of non-$CO_2$ forcings has slowed in recent years, but $CO_2$ emissions are now surging well above the alternative scenario. Prompt actions to slow $CO_2$ emissions and decrease non-$CO_2$ forcings are required to achieve the low forcing of the alternative scenario designed to keep warming less than $1^{O}$C.

"Have we already passed a "tipping point" such that it is now impossible to avoid "dangerous" climate change (Lovelock 2006)? In our estimation, we must be close to such a point, but we may not have passed it yet. It is still feasible to achieve a scenario that keeps additional global warming under $1^{O}$C, yielding a degree of climate change that is quantitatively and qualitatively different than under BAU scenarios.

The "alternative" scenario, designed to keep warming less than $1^{0}$C, has a significantly smaller forcing than any of the IPCC scenarios. In recent years net growth of all real world greenhouse gases has run just slightly ahead of the alternative scenario, with the excess due to continued growth of $CO_2$ emissions at about 2%/year. $CO_2$ emissions would need to level out soon and decline before mid-century to approximate the alternative scenario. Moderate changes of emissions growth rate have a marked effect after decades, as shown by comparison to BAU scenarios. Early decreases in emissions growth are the most effective.

The alternative scenario target, keeping added $CO_2$ to about 80 ppm between 2000 and 2050, may already be impractical due to the 2%/year growth of $CO_2$ emissions in the past decade. However, the net greenhouse forcing could still meet the alternative scenario target via the combination of a still feasible slowdown and reduction of $CO_2$ emissions together with aggressive absolute reductions of $CH_4$ and $O_3$ and a slowdown in the growth of $N_2O$.

Continued rapid growth of $CO_2$ emissions and infrastructure for another decade may make attainment of the alternative scenario impractical if not impossible." (p 2306)

The authors put in a strong case for a more active role for scientists in the climate debate (p 2308): "These stark conclusions about the threat posed by global climate change and implications for fossil fuel use are not yet appreciated by essential governing bodies, as evidenced by ongoing plans to build coal-fired power plants without $CO_2$ capture and sequestration. In our view, there is an acute need for science to inform society about the costs of failure to address global warming, because of a fundamental difference between the threat posed by climate change and most prior global threats. ..

Thus scientists are faced with difficult choices between communication of scientific information to the public and focus on basic research, as there are inherent compromises in any specific balance. Former American Vice President Al Gore, at a plenary session of the December 2006 meeting of the American Geophysical Union, challenged earth scientists to become involved in informing the public about global climate change. The overwhelmingly positive audience reaction to his remarks provides hope that the large gap between scientific understanding and public knowledge about climate change may yet be closed."

***Target atmospheric $CO_2$ – where should humanity aim?***

Hansen et al. (2008): Paleoclimate data show that climate sensitivity is about $3^{O}C$ for doubled $CO_2$, including only fast feedback processes. Equilibrium sensitivity, including slower surface albedo feedbacks, is about $6^{O}C$ for doubled $CO_2$ for the range of climate states between glacial conditions and ice-free Antarctica. Decreasing $CO_2$ was the main cause of a cooling trend that began 50 million years ago, the planet being nearly ice-free until $CO_2$ fell to 450 ± 100 ppm; barring prompt policy changes, that critical level will be passed, in the opposite direction, within decades.

If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that $CO_2$ will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that. The largest uncertainty in the target arises from possible changes of non-$CO_2$ forcings.

The scenario for reducing atmospheric $CO_2$ to 350 ppm by the early 2050s should be achievable through the following "wedges":

1. Moratorium on new coal plants that do not capture and store $CO_2$, and phase out all $CO_2$ emissions from coal plants by 2030. This is a *sine qua non* if the scenario is to be realized.
2. Major programs to improve forestry and agricultural practices: eliminate deforestation by 2015; reforestation to increase uptake of $CO_2$ linearly to reach a maximum by 2030; replacing "slash-and-burn" with "slash-and-char" and phasing in biochar production based on forestry and agricultural waste between 2010 and 2020.
3. An oil-gas-biofuel "wedge" based on energy efficiency, conservation, carbon pricing, renewable energies, nuclear power and other carbon-free energy sources, and government standards and regulations.

"The most difficult task, phase-out over the next 20-25 years of coal use that does not capture $CO_2$, is Herculean, yet feasible when compared with the efforts that went into World War II. The stakes, for all life on the planet, surpass those of any previous crisis. The greatest danger is continued ignorance and denial, which could make tragic consequences unavoidable." (p 17)

Specifically on coral reefs, the paper adds: "Coral reefs are suffering from multiple stresses, with ocean acidification and ocean warming principal among them. Given additional warming 'in-the-pipeline', 385 ppm $CO_2$ is already deleterious.[38] A 300-350 ppm $CO_2$ target would significantly relieve both of these stresses." (p 13)

[38] Hansen and his co-authors (2008) at this point quote 'A world without corals?' by Richard Stone (2007), a journalist with *Science* writing about the combined damage from rising sea temperatures and acidification. Scientists quoted extensively in the *Science* article include Australia's Ove Hoegh-Guldberg and Terry Hughes, and NOAA's Mark Eakin and Alan Strong.

***Second US Senate evidence, 20 years later***

*Exactly 20 years after his appearance before the US Senate in June 1988, Jim Hansen reappeared before that body.*

Hansen (2008): “Today I testified to Congress about global warming, 20 years after my June 23, 1988 testimony, which alerted the public that global warming was underway. There are striking similarities between then and now, but one big difference.

Again a wide gap has developed between what is understood about global warming by the relevant scientific community and what is known by policymakers and the public. Now, as then, frank assessment of scientific data yields conclusions that are shocking to the body politic. Now, as then, I can assert that these conclusions have a certainty exceeding 99%.

The difference is that now we have used up all slack in the schedule for actions needed to defuse the global warming time bomb. The next president and Congress must define a course next year in which the United States exerts leadership commensurate with our responsibility for the present dangerous situation.

Otherwise it will become impractical to constrain atmospheric carbon dioxide, the greenhouse gas produced in burning fossil fuels, to a level that prevents the climate system from passing tipping points that lead to disastrous climate changes that spiral dynamically out of humanity's control.”

“What is at stake? Warming so far, about two degrees Fahrenheit over land areas, seems almost innocuous, being less than day-to-day weather fluctuations. But more warming is already “in the pipeline,” delayed only by the great inertia of the world ocean. And climate is nearing dangerous tipping points. Elements of a “perfect storm,” a global cataclysm, are assembled.

Climate can reach points such that amplifying feedbacks spur large rapid changes. Arctic sea-ice is a current example. Global warming initiated sea-ice melt, exposing darker ocean that absorbs more sunlight, melting more ice. As a result, without any additional greenhouse gases, the Arctic soon will be ice-free in the summer.

More ominous tipping points loom. West Antarctic and Greenland ice sheets are vulnerable to even small additional warming. These two-mile-thick behemoths respond slowly at first, but if disintegration gets well under way, it will become unstoppable. Debate among scientists is only about how much sea-level would rise by a given date. In my opinion, if emissions follow a  scenario, sea-level rise of at least two meters is likely within a century. Hundreds of millions of people would become refugees, and no stable shoreline would be reestablished in any time frame that humanity can conceive.

Animal and plant species are already being stressed by climate change. Species can migrate in response to movement of their climatic zone, but some species in polar and alpine regions will be pushed off the planet. As climate zones move farther and faster, climate change will become the primary cause of species extinction. The tipping point for life on the planet will occur when so many interdependent species are lost that ecosystems collapse.

The shocking conclusion, documented in a paper I have written with several of the world's leading climate experts, is that the safe level of atmospheric carbon dioxide is no more than

350 ppm (parts per million), and it may be less. Carbon dioxide amount is already 385 ppm and rising about 2 ppm per year. Shocking corollary: the oft-stated goal to keep global warming less than two degrees Celsius (3.6 degrees Fahrenheit) is a recipe for global disaster, not salvation.

These conclusions are based on paleoclimate data showing how the Earth responded to past levels of greenhouse gases and on observations showing how the world is responding to today's carbon dioxide amount. The consequences of continued increase of greenhouse gases extend far beyond extermination of species and future sea-level rise.

Arid subtropical climate zones are expanding poleward. Already an average expansion of about 250 miles has occurred, affecting the southern United States, the Mediterranean region, Australia and southern Africa. Forest fires and drying-up of lakes will increase further unless carbon dioxide growth is halted and reversed.

Mountain glaciers are the source of fresh water for hundreds of millions of people.[39] These glaciers are receding world-wide, in the Himalayas, Andes and Rocky Mountains. They will disappear, leaving their rivers as trickles in late summer and fall, unless the growth of carbon dioxide is reversed.

Coral reefs, the rainforest of the ocean, are home to one-third of the species in the sea. Coral reefs are under stress for several reasons, including warming of the ocean, but especially because of ocean acidification, a direct effect of added carbon dioxide. Ocean life dependent on carbonate shells and skeletons is threatened by dissolution as the ocean becomes more acid.

Such phenomena, including the instability of Arctic sea-ice and the great ice sheets at today's carbon dioxide amount, show that we have already gone too far. We must draw down atmospheric carbon dioxide to preserve the planet we know. A level of no more than 350 ppm is still feasible, with the help of reforestation and improved agricultural practices, but just barely -- time is running out.

The steps needed to halt carbon dioxide growth follow from the size of fossil carbon reservoirs. Coal towers over oil and gas. Phase out of coal use except where the carbon is captured and stored below ground is the primary requirement for solving global warming."

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[39] The melting of tropical glaciers is a striking indicator of the current global warming trend. A comprehensive review (Steig 2005) shows glaciers in retreat throughout the Tropics – in South America, Africa, and the Himalayas. "The case of Quelccaya, in the Andes, is especially interesting, because it provides direct evidence of an unusual recent warming trend. When the summit core was first drilled in 1976, the chemical composition of the ice showed well-preserved annual layering throughout its depth, accounting for a time span of 1500 years. When attempts were made to update the record by redrilling in 1991, it was found that the annual cycle had been wiped out over the top 20 meters of the core by percolation of meltwater from extensive melting of the ice surface since 1976. Melting of this sort had not occurred at the summit at any time during the previous 1500 years, and indicates an increase of 150 m, between 1976 and 1991, of the altitude at which significant melting occurs. .. The widespread retreat is all the more notable because tropical mountain glaciers are old. They have survived thousands of years of natural climate fluctuations, only to dwindle at a time when other climate indicators — notably surface temperature — are showing the imprint of human influence on climate. Quelccaya is at least 1500 years old, Dasuopu [in the Himalayan subtropics on the Qinghai-Tibet plateau] is 9000 years old, and Huascaran [in Peru] has seen 19000 years. A date for the ultimate demise of these glaciers has not been fixed, but the Northern Ice Field on Kilimanjaro may be gone in as little as twenty years, after having survived the past 11,000 years."

## OCEAN ACIDIFICATION

James Hansen would undoubtedly agree that the impact of ocean acidification goes way beyond coral reefs. It has vast implications, especially for the carbon cycle of the Southern Ocean. "If $CO_2$ emissions continue on current trends the aragonite saturation horizon will rise to the surface of the oceans before the end of this century, making aragonite skeletons unstable throughout the water column over the entire Southern Ocean." (Raven et al. 2005, p 29) "[This] will have further large-scale ramifications for .. other interconnected ecosystems." (p 30)

A table in the paper (p 13) shows average oceanic pH levels falling from 8.18 in pre-industrial times to 8.07 today, to 7.92 if the atmospheric $CO_2$ level doubles, 7.77 if it triples, and 7.65 if it quadruples. The table also shows the associated saturation levels of calcite and aragonite, with the warning that even a modest increase in atmospheric $CO_2$ is very likely to cause the Southern Ocean to become under-saturated with respect to aragonite. Reinforcing the statement above, they write (p 13): "This would lead to severe consequences for organisms that make the aragonite form of $CaCO_3$ shells and plates."

One of Raven's co-authors (2005) summarizes the prospects: "Basically, the ocean would be much too acidic for corals and coral reefs to maintain the calcification rates required to keep up with rates of physical and biological erosion. This will essentially mean that reefs begin to crumble and disappear under these forces. It is important to realize that many other systems are sensitive to pH (fish metabolism, photosynthesis, bacterial systems crucial to biogeochemical cycles, larval development, and a myriad of other pH sensitive processes). This is a veritable house of cards where small changes in pH can lead to enormous changes within ocean ecosystems." (Ove Hoegh-Guldberg, personal communication, June 2010.)

Moreover, ocean acidification has effects on biological systems which are only just being identified and while subtle can be quite profound in their implications. For example, acidified conditions lead to problems in the way fish navigate. Testing the effects that ocean acidification from elevated levels of atmospheric $CO_2$ could have on the ability of larvae to detect olfactory cues from adult habitats, it has been found that larval clownfish reared in seawater with a pH of 8.15 discriminated between a range of cues that could help them locate reef habitat and suitable settlement sites. This discriminatory ability was disrupted when larvae were reared in conditions simulating $CO_2$-induced ocean acidification. "If acidification continues unabated, the impairment of sensory ability will reduce population sustainability of many marine species, with potentially profound consequences for marine diversity." (Munday et al. 2009, p 1848)

## CLIMATE CODE RED

Australian businessman and climate-policy analyst David Spratt and ecological economist Philip Sutton in 2008 published a book which has gained a wide international readership for its "red alert" message on climate change (Spratt and Sutton 2008). An appendix to the book sets out a *Climate Code Red* strategic planning scenario (pp 257-266).

The authors say that this scenario is one of several that could be drawn from the book, and that it differs from other climate-change advice: It considers the climate threat to be more urgent than most analysts suggest, and it proposes a full-strength response to achieve a return to a safe climate, “rather than merely a slower onset of catastrophe.” (p 258)

The scenario is triggered one summer, in 2013 or before, by the melting of all the Arctic sea-ice, an event repeated each summer thereafter. This initiates a $5^{O}C$ rise in regional temperatures, due to the replacement of light-reflective ice by heat-absorbing dark seas. Accelerated melting of the Greenland ice sheet follows, which if allowed to progress is predicted together with other factors to increase global sea levels by up to five meters by 2100. The rising Arctic temperature would also accelerate the melting of permafrost soils, releasing additional large amounts of greenhouse gases, particularly in the second half of the century.

The current climate trajectory already commits the planet to a long-term temperature increase of $3^{O}C$. There will be an ever-increasing impact of positive feedbacks which will continue the process already begun to reinforce and amplify human-caused global warming; however, the opposite is also true that human actions resulting in sustained climate cooling will trigger natural processes that drive further cooling. The Arctic ice itself could be restored fairly quickly as part of these cooling processes.

The scenario is based on scientific evidence that a safe-climate future is not possible if the Arctic icecap is permanently absent during the northern summer. To restore the Arctic ice the global temperature needs to drop by at least $0.3^{O}C$ from the 2008 level, and the long-term level of greenhouse gases in the air must be reduced to 300-325 ppm $CO_2$. To achieve this means setting the emissions target at zero and take other measures as well to reduce the heating effect of excess $CO_2$ already in the air, which will in turn restore the Arctic summer ice-cap.

In so doing, however, we also reduce the release of aerosols that accompany fossil-fuel combustion. Aerosols mainly act as a cooling agent in the atmosphere but last only a couple of weeks there, whereas carbon dioxide may act as a warming agent for hundreds of years. So if we stop burning fossil fuels, there will be a once-off temperature increase of at least $0.7^{O}C$, because the accumulated effect of past carbon emissions continues at the same time as the cooling effect of recently emitted aerosols is rapidly lost. A partial remedy could be a major effort to reduce the emission of short-lived greenhouse gases such as methane and black carbon. [40]

[40] Aerosols differ from greenhouse gases: they are particles of organic carbon, sulfates and nitrates, and ashes and dust from smoke, manufacturing, and windstorms. As this particle pollution is now being brought under control, the retarding influence of so-called *global dimming* is being lost. The leading British climate scientist Peter Cox has identified this as a threat of even more accelerated warming, and suggests that the previously masked true impact on climate change of polluting activities is only now being revealed (Sington 2009).

One of the aerosols, however, works in the opposite direction by trapping heat in the lower atmosphere: *black carbon*, which is a component of soot. It has been identified as the second-leading cause of global warming after carbon dioxide (contributing 16%), ahead of methane. Because it stays only a short time in the atmosphere, controlling this pollution is considered to be the fastest method of slowing global warming, as well as being beneficial to human health (Jacobson 2007). Over 40% of black carbon emissions into the atmosphere comes from open forest and savanna burning, with the remainder due to diesel engines for transport and industrial use, residential solid fuels such as wood and coal burned using traditional technologies, and industrial processes mainly from the use of small boilers (Bond 2007).

The removal of atmospheric carbon through such means as growing biomass, converting it to agricultural charcoal (biochar) sequestered in agricultural soils, and sequestering the $CO_2$ in geological structures, would take decades and is likely to prove too slow.

The *Climate Code Red* scenario is based on the assumption that the industrial transformation needs to be as fast as possible because (a) the planet is already too hot, as is evident in the Arctic, (b) rapid warming will tear apart natural ecosystems, (c) extreme weather events are already affecting many people and nations, and (d) many unpredictable possibilities could arise as a result of current greenhouse gas levels and near-term temperatures: impact on tropical rainforests, destabilizing the West Antarctic ice sheet, and releasing warming feedbacks so strong that they become uncontrollable by human effort.

The necessary industrial and economic restructuring needs to be completed in about a decade to stop atmospheric greenhouse gas levels from rising and to initiate the accelerated removal of excess $CO_2$ from the air. This may not be possible within such a short period.

There are two key issues:

1. We must stop emitting greenhouse gases quickly, but the aerosol effect will then cause a serious short-term temperature rise
2. We cannot allow high temperatures to persist for too long, otherwise too much damage will be done.

In light of these issues, additional strategies are needed, such as direct cooling strategies to increase the reflectivity of the planet. These include actions to increase the cover of highly reflective cloud (by boosting plankton growth in the oceans or by re-establishing forests), or injecting aerosols into the upper atmosphere where they are not washed out by rain.[41]

Three enormous tasks will absorb a sizable proportion of the global economy's productive capacity, particularly during the decade of initial physical restructuring:

1. Making the global move to zero greenhouse-gas emissions in as short a period as is environmentally safe
2. Drawing down as many billions of tons of carbon from the air over the fewest possible number of decades
3. Direct cooling of the Earth for as long as necessary.

This will not be possible under normal political conditions. The success of the scenario will depend on sufficient action being taken by nations that produce most of the emissions and have the economic and physical capacity to contribute to the drawdown of $CO_2$ and to direct cooling. To make this commitment socially possible, nations must conclude that they need to go into emergency mode, similar to the challenge among the Allied nations during World War 2. But while the threat was palpable then, climate change is not yet generally perceived to be as urgent.

All countries will therefore struggle to achieve the needed change "unless they engage their communities in a deliberate process to learn about the climate-change issue, and help them

[41] The realism, or otherwise, of geoengineering technologies is discussed in Appendix 6.

to reach a genuine understanding of the severity of the problem and the necessity for urgent action on a huge scale." (p 265)

***The "new business-as-usual"***

The entire argument in Spratt and Sutton (2008) is that the current situation requires emergency action – quoting UN secretary-general Ban Ki-moon on top of page one that "for emergency situations we need emergency action." The scenario outlined in the previous section is about initiating emergency action; the alternatives are calamitous.

They point to a damaging perception in their Chapter 20, *The new* . "There is a new color in fashion: warm-climate green. Pastel in tone and hard to miss, you'll find it in newspapers, on television and, especially, in lifestyle magazines, from fashion and travel, to house and garden. From corporate responsibility to bottled water, climate-friendly images and products reassure us that it is okay to consume as never before." (p 179)

In other words, a host of products, services and market mechanisms have been developed in response to global warming, "but they are not all necessarily about helping create a safe climate. These include "clean" coal [*the new mainstay of coal miners, power generators, and the politicians who defend them*], current-generation biofuels [produced from food crops], voluntary carbon offsets, and two arrangements under the Kyoto Protocol: carbon trading, and the Clean Development Mechanism." (p 180)

The authors maintain that the Clean Development Mechanism has been misused because the scheme has mainly granted carbon credit to projects that would have been built anyway (p 189). Carbon trading is another element of the larger carbon market set up by the Kyoto Protocol, in which a total emissions target is set for an industry or region and decreased over time, thereby purporting to create an incentive to switch to low-pollution technology. Spratt and Sutton show that the initial permit pool of the European Union Emissions Trading Scheme was set too high, which resulted in some of the biggest polluters being rewarded with hundreds of millions of dollars by selling surplus permits. They point to other flaws as well (pp 190-191).

Adding all the perceptions of consumers based on "green" marketing claims, the "new BAU" mode, while often a well-intended response to the climate and sustainability crisis, may be lulling our societies into a false sense of security – reinforced by the highly publicized accusations of alarmism against those advocating urgent action to tackle climate change.

## NEW THEME FOR SAFE CLIMATE CHANGE POLICY: <350

Following James Hansen's lead, <350 [ppm $CO_2$] became a prominent slogan in 2009, and it is appropriate to conclude an appendix on the science-based deteriorating global outlook for climate change in the context of other opinions on climate change in 2009. Hansen's advocacy inspired the formation in 2007 of a worldwide non-government organization, *350.org*. It declared October 24, 2009, to be International Day of Climate Change, and helped organize over 5,200 actions in 181 countries on that day.[42]

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[42] http://www.350.org/.

This highly visible activity contrasts starkly with the United States public and legislature seeming to turn markedly against climate change during 2009, a reversal of previous trends also seen in Australia and elsewhere. The apparent rise in the number of climate change deniers may be more a matter of ill-informed short-term concerns about the economy crowding out what is seen as a less immediate threat, with US unemployment soaring above 10% in late 2009. But it has probably delayed the introduction of national cap-and-trade schemes in the US and Australia to beyond the COP-15 meetings on climate change in Copenhagen in December 2009.

Harvard economist Martin Weitzman points to “the extreme uncertainty of extreme climate change” (Weitzman 2009), writing that “the probability of a disastrous collapse of planetary welfare from global warming seems non-negligible, even if this low probability is very difficult to quantify.” As further discussed in Appendix 5, Weitzman has noted that the relevant probability distributions have “fat tails”, giving more weight to extremes than is the case in standard normal distributions. ”The tails of the relevant probability distributions should not be ignored because they are likely to be fat with probability and important.”

The contrasting perceptions of climate change by scientists and environmentalists, versus many of the general public and their political representatives, are part and parcel of the assessment of how the four scenarios could plausibly evolve over the coming decade or two.

***Faster change and more serious risks***

Will Steffen is the executive director of the Climate Change Institute of the Australian National University. The subtitle of his report to the Australian Department of Climate Change (Steffen 2009) provided the heading of this section. Steffen’s objective is similar to the intent of this appendix: “to review the science of climate change since the publication of the IPCC’s AR4, with an emphasis on areas of science that are changing rapidly and have significant consequences for our understanding and analysis of critical issues for policy and management.” (p 3) The following list is drawn from the executive summary (p 1):

- The climate system appears to be changing faster than earlier thought likely.
- The majority of uncertainties surrounding climate science operate towards more rapid and severe climate change and thus towards more costly and dangerous impacts.
- The risk of continuing rapid climate change is focusing attention on the need to adapt, and the possible limits to adaptation, including the implications of possible sea-level rise,[43] the threat of recurring severe droughts and extreme climatic events, and the impacts of increasingly acidic oceans and higher ocean temperatures on marine resources and iconic ecosystems.

[43] Steffen goes along with the upper-limit IPCC projection of 0.8 m by 2100, whereas Rahmstorf (2007) projected a range from 0.5 m up to 1.4 m based on “a semi-empirical relationship .. that connects global sea-level rise to global mean surface temperature.” Referring to this, Steffen comments: “Although such statistical models do not include the process understanding that forms the basis for the model projections reported in the IPCC assessments, they may suggest that additional processes not yet incorporated in the more complex models are becoming important.” (Steffen 2009, p 8)

- Climatic features such as extreme events, abrupt changes, and the nonlinear behavior of climate system processes will increasingly drive impacts on people and ecosystems. Despite these complexities, effective societal adaptation strategies can be developed by enhancing resilience or, where appropriate, building the capacity to cope with new climate conditions. The need for effective reduction in greenhouse gas emissions is also urgent, to avoid the risk of crossing dangerous thresholds in the climate system.

- Long–term feedbacks in the climate system may be starting to develop now; the most important of these include dynamic processes in the large polar ice sheets, and the behavior of natural carbon sinks and potential new natural sources of carbon, such as the carbon stored in the permafrost of the northern high latitudes. Once thresholds in ice sheet and carbon cycle dynamics are crossed, such processes cannot be stopped or reversed by human intervention, and will lead to more severe and ultimately irreversible climate change from the perspective of human timeframes.

Steffen in his concluding section on "over-the-horizon research" (pp 42-45) uses the term "tipping element" for a set of large-scale components of the climate system that could undergo abrupt or irreversible change under anthropogenic forcing. The term was introduced by Lenton et al. (2008) to describe large-scale components of the Earth system that may pass a tipping point or critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system.

The greatest and clearest threat of such events happening, according to analysis of tipping elements by Lenton and his co-authors, is to the Arctic with summer sea-ice loss likely to occur long before, and potentially contributing to, the melting of the Greenland ice sheet. Tipping elements in the tropics, the boreal zone of Siberia and Canada, and West Antarctica are surrounded by large uncertainty but, given their potential sensitivity, *constitute candidates for surprising society* (badly). The archetypal example of a tipping element, the cessation or reversal of the North Atlantic thermohaline circulation, appears to be a less immediate threat, but its long-term fate under significant warming remains a source of concern (Lenton et al. 2008, p 1792).

***Economics of 350***

This is the title of a study of the benefits and costs of climate stabilization (Ackerman et al. 2009) which proposes to reach 350 ppm $CO_2$ without relying on the negative net emissions assumed in the scenario by Hansen et al. (2008) described in a previous section. The study presents "a less demanding but still ambitious trajectory which does not require the world to achieve negative net emissions;" assuming a climate sensitivity of $6^{O}$C (to a doubling of atmospheric $CO_2$ as estimated by Hansen, but twice the IPCC's assumption in 2007), the scenario reaches 350 ppm $CO_2$ by 2200. Both scenarios assume success, within this century, in converting the world energy system to carbon-free sources.

"Our scenario represents the most ambitious schedule that we can imagine without relying on negative emissions: emissions are reduced to 54% of 1990 emissions by 2020 and 3% by 2050. The conversion to renewable energy systems would have to be complete and the world economy would have to be virtually free of carbon emissions by mid-century, a more demanding goal than any of the leading policy proposals under discussion today."

The study is based on economic modeling using the DICE model developed by William Nordhaus. With low discount rates and using a climate sensitivity of 6 $^{O}$C and a high damage exponent of 4 or 5, the results come close to the Hansen scenario. The study is non-specific as to technological change beyond assuming a complete switch to renewable energy within the 21st century, and assuming no overall net reduction which might result from improved land management systems using already available afforestation and biochar technologies.

Recent estimates of net annual costs of global scenarios leading to 350 ppm $CO_2$ are between 1% and 3% of world output. Assuming the cost is 2.5% and that the world is also growing at 2.5% pa this is equivalent to foregoing one year of growth, or doubling GDP in 29 rather than 28 years (p 5). This is not dramatic in a long-term context but we may add to the judgments made in the study that the resistance we are seeing today to cap-and-trade and other climate change-related arrangements has to do with structural adjustment to the economy rather than increased long-term costs.

Ackerman et al. conclude (2009): "The constraints on allowable $CO_2$ emissions, for stabilization at a level as low as 350 ppm, are painfully tight .. . A realistic policy scenario, therefore, is almost certain to call for not only maximum progress in pursuing energy efficiency and promoting renewable energy, but also for measures that remove carbon from the atmosphere. Large-scale reforestation (and of course ending deforestation) is one approach; developing biomass energy, with capture and storage of the carbon emissions, is another. The technologies that will be needed, over the coming century of intensive effort, do not yet exist in commercially viable forms, if at all. Yet the development of new technology is itself heavily influenced by public policy. It is not surprising that the detailed studies of a 350 ppm $CO_2$ stabilization trajectory involve projections of technology choices, and speculation about the technologies that will be available in the second half of this century. Several major research groups project that the necessary choices will be available, at a cost the world can clearly afford to pay." (p 35)

"The world is taking important initial steps towards addressing the climate crisis, with increasingly widespread discussion of the need to avoid 2°C of warming. What is less widely recognized is that, according to recent scientific research, avoiding that temperature limit likely requires stabilization at about 350 ppm of $CO_2$. Such a low target requires a large-scale, continuing effort throughout this century, and the development of major new technologies, as well as appropriate price mechanisms. Predicting the future is challenging, because it has not yet happened; predicting a century of technological and economic change is inescapably fraught with uncertainty. Nonetheless, the best available estimates imply that we can, indeed, afford the economics of 350. What we cannot afford is too little climate policy, too late." (p 36)

***Coral reefs and 350***

This appendix on changing scenarios concludes with a paper on "the critical importance of <350 ppm $CO_2$" for coral reefs (Veron et al. 2009). Coral reefs were among the first organisms to become damaged by climate change, probably harking back to a time when atmospheric $CO_2$ levels were as low as 320 ppm back in the late 1960s. Because it takes a decade or more for sea water temperatures to respond to the atmospheric change, the first records of mass coral bleaching were in 1978-79. Later, at 340 ppm, sporadic but highly destructive mass bleaching occurred worldwide, often associated with El Niño events (temperature increases of 1-2$^{O}$C above the long-term summer maxima destabilizes the relationship between the host coral and their symbiotic zooxanthella algae). At today's levels around 387 ppm, allowing a lag time for sea temperatures to respond, most reefs worldwide are probably committed to an irreversible decline.

Veron et al. (2009) provides an up-to-date summary of the economic importance of coral reefs to coastal societies around the world, and their vital importance as a large component of the Earth's total biodiversity – the threat of their demise is "something never experienced before in human history." (p 1429)

Exacerbating the image of rising sea temperatures, the increasing quantities of $CO_2$ are dissolved in the ocean as part of the carbon cycle, forming carbonic acid ($H_2CO_3$) which releases hydrogen ions ($H^+$), which lowers the pH making the ocean more acidic. The ocean pH, while still highly alkaline, has already dropped from about 8.2 to 8.1, which is more serious than it appears because the scale is exponential. As more $CO_2$ is dissolved, the pH could drop more significantly over the coming years and decades, to perhaps 7.7 in a scenario. The lead author, Charlie Veron, told the *Catalyst* program of the main Australian public television broadcaster in June 2009: "It is the most serious problem of climate change. It is the big one." [44]

The acidification acts directly on organisms with calcareous skeletons, from phytoplankton to mollusks to reef-building corals. Corals are especially vulnerable because their skeleton is made of aragonite, which is more soluble than the more common carbon carbonate, calcite.

The paper highlights three issues of particular importance for the future of coral reefs:

1. The role of multiple stressors, principally rising sea-levels, increasing numbers of high-intensity storms, deteriorating water quality and various biotic impacts which are ultimately associated with pollution and other human activities.
2. Resilience is the capacity of a reef to recover from major disturbance. Increased frequency of El Niño events will degrade the reef which will have a strong influence on its resilience. Overfishing and degraded water quality reduce the resilience to bleaching – chronically stressed reefs in the Caribbean and elsewhere are now at high risk of reverting to semi-permanent algal or cyanobacterial communities, whereas reefs remote from additional human stresses can make rapid recoveries.
3. Reefs are likely to be the first major planetary-scale ecosystem to collapse in the face of climate change. This raises the question whether such a collapse will have wider implications – domino effects. "It is already clear that the effects of ocean acidification will directly impact all carbonate-dependent taxa. .. Research on these issues is still in its infancy, but the enormity of the threat is nevertheless real." (p 1433)

[44] http://www.abc.net.au/catalyst/stories/s2029333.htm.

> Closer to home, the failure of reefs will have knock-on effects on associated ecosystems, including neighboring island biota and estuarine habitats, seagrass beds, mangroves, and the animals and other organisms living there.

To get below an atmospheric $CO_2$ level of 350 ppm will be extremely challenging, when cumulative carbon emissions have already committed us to a level exceeding 380 ppm. “Thus, to return to a safe level for corals will demand maintaining, enhancing and probably creating carbon dioxide sinks in addition to strong cuts to $CO_2$ emissions. If such a strategy is pursued, it will be critical to consider all possible benefits and limitations and employ great caution, before allowing planetary scale carbon dioxide removal schemes to proceed.” (p 1433) Geoengineering options such as ocean fertilization (see Appendix 6) still have to prove their effectiveness and may risk serious side effects. Alternative options which involve reflecting part of the sun’s radiation back into space, will have no effect on ocean acidification.

The alternative scenarios implied in Veron et al. (2009) can be summarized in the following two quotes, both from p 1433:

*What must be done*: “The extreme gravity of the current predicament is now widely acknowledged by reef and climate scientists. It is also acknowledged that only drastic action starting now will prevent wholesale destruction of reefs and other similarly affected ecosystems.”

*Business-as-usual*: “As custodians of geological history, reefs offer both immense geological evidence and stark recent testimony to the potentially catastrophic effects of destabilizing global climate. Although, being carbonate platforms, they are particularly sensitive to disruptions of the carbon cycle, their demise is symptomatic of damage to the entire biosphere as this cycle plays a dominant part in all ecosystems. When taken together, the abruptly accelerating deterioration of terrestrial and marine ecosystems and the increasingly disturbing global extinction rates may eventually become indistinguishable from the records of mass extinctions captured in the remains of long-fossilized coral reefs. The difference is that this time humanity will have been the cause and also one of the species to suffer.”

# ADDENDUM 1: PROLIFERATING REFERENCES TO CLIMATE CHANGE

## AN EXAMPLE

On 28 February 2009 the popular science magazine, *New Scientist*, published an article describing the devastating effects of a “four-degree world” on world climate, economy, geography, and population size and distribution (Vince 2009). It said that a “$4^{O}$C rise could easily occur” and quoted a former chair of the IPCC, Bob Watson, warning that the world should work on mitigation and adaptation strategies to prepare for $4^{O}$C of warming. Humankind would survive but only one billion may remain by 2100.

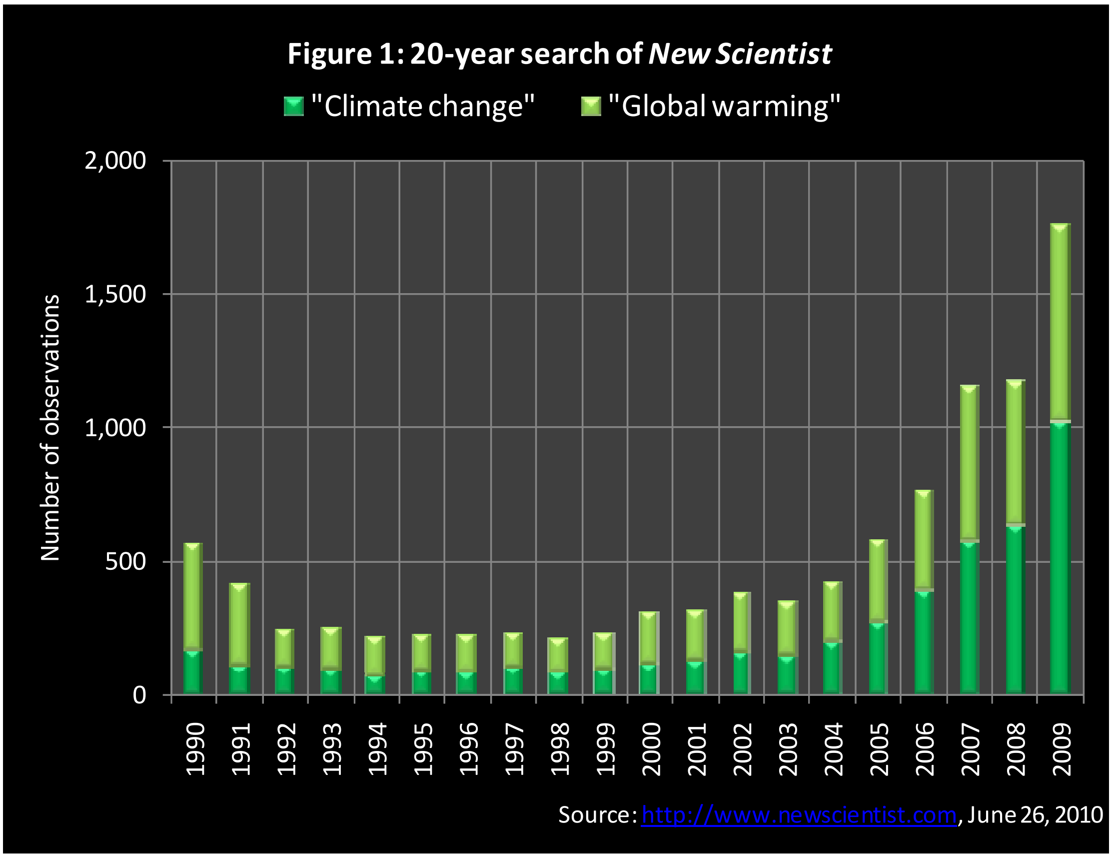


**Figure 1: 20-year search of *New Scientist***

One may query the note of inevitability the article seems to convey, since successful international action to avoid the “four-degree world” may happen. But *New Scientist* is a respected popular science magazine, and climate change has become an extraordinarily urgent issue – in fact, searching for the keywords “climate change” and “global warming” in successive annual volumes of the magazine demonstrates a strong increase in the number of observations since 2004 (Figure 1), coupled with a rise in the sense of urgency they convey. The publicity engendered during the run-up to the Copenhagen conference in December 2009 may explain some of the increase but the quarterly observations for the first half of 2010 remain above the first half of 2009 (Table 1).

Even if the second half of 2010 proves not quite matching the extraordinary second half of 2009, it may be concluded that climate change, judging from this indicator, remains a vital issue for anyone interested in or participating in scientific research. The publicity and debate surrounding the forthcoming COP-16 conference in Cancún, Mexico, in December may not be as concentrated as was the case before the Copenhagen conference.

Table 1: Quarterly search results, *New Scientist*

| Quarter | "Climate change" | "Global warming" | Total obser-vatioms |
|---|---|---|---|
| Mar-08 | 114 | 109 | 223 |
| Jun-08 | 163 | 141 | 304 |
| Sep-08 | 174 | 155 | 329 |
| Dec-08 | 185 | 138 | 323 |
| Mar-09 | 204 | 127 | 331 |
| Jun-09 | 162 | 111 | 273 |
| Sep-09 | 319 | 247 | 566 |
| Dec-09 | 339 | 228 | 567 |
| Mar-10 | 195 | 139 | 334 |
| Jun-10 | 182 | 121 | 303 |
| Year ended | | | |
| Dec-08 | 636 | 543 | 1,179 |
| Jun-09 | 725 | 531 | 1,256 |
| Dec-09 | 1,024 | 713 | 1,737 |
| Jun-10 | 1,035 | 735 | 1,770 |

Source: See Figure 1

This search was originally conducted with "climate change" as the only keyword. The addition of "global warming" is desirable because there has been a shift in terminology between the two terms, which are sometimes used interchangeably, if incorrectly. In the 1990s, "global warming" accounted for an average of 62% of the total number of observations, in the first decade of the 2000s for 53%, and in the year 2009 for only 42%. The wider concept of climate change was taking over.

The items covered by Figure 1, mostly "news" followed by "features", may have been boosted by a special supplement on 28 April 2001 containing three doomsday-like scenario articles on climate, population, and pollution, viewed in retrospect from 2100 (Walker 2001, Pearce 2001, and MacKenzie 2001). However, the count for 2001 was not hugely different from what had been experienced during the 1990s, and it was no larger than the observation for 2000.

The general impression is that scientists and science journalists have been alerting political and other opinion leaders to the danger of climate change since about 2004 at an increasing rate. The number of items accelerated from 2005-06, and there may have been a renewed emphasis on worst-case scenarios such as Vince (2009) and MacKenzie (2008), both quoting a range of authoritative scientific evidence. Coghlan (2009) reports that global warming could suffocate the sea for hundreds of thousands of years to come, based on a paper in *Nature Geoscience* (Shaffer et al. 2009).

During the period reviewed, one article in 2003 titled *Doomsday scenario* suggested that feedback effects could cause "abrupt and irreversible changes" (Pearce 2003). Other articles dealt with Antarctic ice breakup (Jones 2002) and arctic melt running 20 years ahead of climate models (Powell 2008b), the risk of releasing vast quantities of ancient methane (Hecht 2002), ocean acidification (Hecht 2003, Henderson 2006 focusing on coral, Powell 2008a), the risk of major sea-level rise (Hansen 2007b), and "returning to coal" due to the rise of China's and India's economies (Coghlan 2007).

The general impression is that climate change is seen as a strongly increasing threat judging from a growing number of new features such as those just listed. Huge cuts in emissions were needed to curb climate change (Hogan 2005), while Holmes (2005) reported that the heat already stored in the oceans made climate change inevitable.

## CONCLUDING OBSERVATIONS

In theory, there are two possible reasons why global climate change appears to be more of a threat in 2009 than it was 10 years ago.

One is that scientists know more about the mechanisms, including the positive feedbacks or nonlinearities which have been part of climate models since 2000.

The other increasingly acknowledged reason is that there has in fact been an ongoing destabilization in the climate mechanisms, causing a real change in the tempo at which the climate is affected by positive feedback. Factors such as the accelerating breakdown of ice sheets show that the second reason is important, and there is much other evidence along similar lines. It's not just that we have a built a better knowledge base; the tightening from a 450 to a 350 ppm $CO_2$ stabilization (with a reasonable hope that the global average temperature will then be limited to $2^{O}C$ above pre-industrial levels) appears to be highly justified as worst-case scenarios creep up the probability distribution towards more likely levels.

On the positive side, and despite the failure of the Copenhagen UNFCCC meeting in December 2009 to secure a binding international agreement, governments have become more aware of the need to intensify mitigation and adaptation efforts, offering some hope that the stabilization level will be actually reached at $2^{O}C$ rather than at riskier higher levels, despite all the political and economic difficulties. This realization is of fundamental importance for the global community.

The increasing interest of industry around the world to engage in ventures involving renewable and nuclear energy, including China's efforts to introduce "cleantech" technologies at a massive scale, is also fundamentally important. The implications are best viewed in the build-up of alternative scenarios in the main Florida Keys report.

## ADDENDUM 2: MURPHY'S AMERICAN SCENARIOS

The epilogue of Cullen Murphy's *The New Rome* (2007) considers the similarities and differences between the United States and the late Roman empire. He says on p 198: "If .. you could put early twenty-first-century America into fast-forward, what could you see? Certain futures are all too plausible; we've made a start on each one of them."

### FORTRESS AMERICA

"As perceived threats to the country grow more insistent and varied, all of society increasingly bends toward a particular vision of homeland defense. We watch as local police forces, the educational system, even pop culture, bit by bit acquire a vaguely martial cast. Spending on domestic programs is diverted to national security. Economic life orients itself increasingly around the requirements of the military and the intelligence apparatus, and of our far-flung protectorates. Individual rights and freedoms take a back seat to the government's need to know. .. The executive branch is paramount, the other two branches having evolved into useless but still-detectable appendages, like a whale's vestigial limbs." (pp 198-199)

### THE CITY-STATE SCENARIO

This scenario is "already emerging in many parts of the world. As the government in Washington becomes more and more unwieldy (and resented), and as its foreign policies drag the country into dangers that many of the country's components would just as soon avoid, the great cities gradually assert themselves. Los Angeles, New York, Miami, Seattle, Chicago – these and a few other places, including Washington, are America's prime source of wealth and creativity even now. They animate entire regions with their economic and intellectual power, and stamp those regions with their cultural characteristics. They pursue domestic policies – on the environment, medical research, social issues – sharply at variance with those of Washington. .. Now, on fast-forward, we see them becoming *de facto* city-states, emerging organically out of the nation's moldering timber like the barbarian kingdoms of late antiquity. Of course, without the flywheel of Washington there is strife – over borders, resources, amenities. City-states compete even more ferociously than they used to for investment from abroad." (p 199)

### THE BOARDROOM SCENARIO

This scenario "is the extension of corporate ownership to ever larger areas of ordinary life, not just in America but worldwide. .. On fast-forward we see the rise of corporate feudalism on a global scale. The world's biggest corporations are already powerful transnational actors in an era when many problems demand transnational management." And while American cities, if they were countries, would account for 47 of the 100 largest economies, "in this case, of the world's hundred largest "economies" half are not countries but private companies. Some of them command small armies, and quietly rule significant swaths of the planet. Others manufacture the weapons used by "real" countries, including America. A small number of companies produce all the oil and gas. A small number control the world's freshwater resources. .." (pp 199-200)

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# APPENDIX 4: LIMITS TO ECONOMIC GROWTH

## INTRODUCTION

### NO MEASURE OF LIMITATIONS TO CONVENTIONAL ECONOMIC GROWTH

The IPCC projections of global GDP and population in the *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000) apparently do not consider the possibility that a world with highly elevated temperatures and other consequences of climate change might find it difficult to grow at the rates projected. The scenario builders seem to have assumed that such problems can be solved through technology, which according to the SRES summary for policymakers was defined as “at least as important a driving force as demographic change and economic development.”

There is no discussion in the IPCC literature (that we have been able to find) of how seven billion people or more would be able to live comfortably, or at least tolerably, in the global growth scenario A1, in temperatures four or more degrees Celsius above pre-industrial levels (comparable to the warming from the ice age to the $19^{th}$ century). This might possibly work for the richest nations but it stretches credibility to extend the assumption to all nations – despite the embedded assertion that average incomes in developing and rich nations would converge in the high-growth scenario A1.

### NO MEASURE BEYOND THE CONVENTIONAL ECONOMIC STATISTICS EITHER

Another problem is regarded by many as a glaring omission. It is relevant because the underlying implication is that conventional measures of economic growth are too high because they omit reference to the depletion of the natural capital of the planet. Crudely put, our apparently high economic growth rate is sustained because humans have been able to consume in a short time span the accumulated capital made up of non-renewable resources millions of years old.

Despite many years of ongoing research into the matter, only modest progress has been made on developing national accounting statistics that take environmental degradation into account (UNSD 2009). The main reason seems to be the complexity, lack of hard data, and difficulty of obtaining agreement to get a system of standardized accounts going. There have been attempts to build in statistics showing the change in mineral stocks and the like, but putting a value on ecosystems and on a healthy atmosphere has been considered too hard.

As a possible alternative, or supplement to the conventional statistics, the Wentworth Group of Concerned Scientists in Australia has produced a blueprint of a system of standardized environmental accounts (Cosier 2008). The group advocates a regional data collection and reporting framework that measures the health of the following five asset classes as a starting point:

1. Land (native vegetation, native fauna, soils)

2. Water (rivers, wetlands and estuaries)

3. Atmosphere (greenhouse gas emissions which cause climate change)

4. Marine and coastal resources (fish stocks, reefs, beaches)

5. Towns and cities (air quality, waste, water use, consumption).

Any such extension would fall outside a conventional national accounting system, which has indeed been the stumbling block for any real progress on the matter. [45] As far as the Florida Keys project is concerned, we can do little except pointing to the issue, and suggesting that proper accounting for environmental degradation would put a brake on excessive reliance on unbridled economic growth by providing adjustments for matters such as humankind's rapid consumption of resources it took millions of years to accumulate, and the real value of ecosystems and how they interact. Regrettably there is no agreed approach. We are stuck with conventional measures of economic product, as was the IPCC, and can only continue to point to the scientific evidence of degradation and the possible consequences thereof.

Perhaps the most promising development is a major report published in September 2009, which not only seeks ways of going "beyond GDP", as one commentator expressed it (Holderness 2009), but involved two Nobel Prize-winning economists in recommending how. The background is explained in the first paragraph of the 291-page report (Stiglitz, Sen and Fitoussi 2009): French President Sarkozy, "unsatisfied with the present state of statistical information about the economy and the society", asked the economists to create a Commission on the Measurement of Economic Performance and Social Progress (CMEPSP), chaired by Stiglitz, advised by Sen, and coordinated by Fitoussi.

"The Commission's aim has been to identify the limits of GDP as an indicator of economic performance and social progress, including the problems with its measurement; to consider what additional information might be required for the production of more relevant indicators of social progress; to assess the feasibility of alternative measurement tools, and to discuss how to present the statistical information in an appropriate way."

A couple of excerpts from the executive summary set the stage:

"To focus specifically on the enhancement of inanimate objects of convenience (for example in the GNP or GDP which have been the focus of a myriad of economic studies of progress), could be ultimately justified – to the extent it could be – only through what these objects do to the human lives they can directly or indirectly influence. Moreover, it has long been clear

[45] The main developmental work is carried out by the London Group of Environmental Accounting, created in 1993 to allow statisticians to share their experience. The 2008 meeting of the group lists 28 presentations, spread across an array of specific subjects. Most deal with specific technical problems, including two on the value of time passing (discounting) as natural resources are depleted (Comisari 2008, Pedersen 2008). Another contribution deals with the harmonization of IPCC statistics of greenhouse gas emissions and energy statistics (Treanton 2008). But there are no indications of how to measure the value of, say, ecosystem degradation which would be more compatible with Cosier's asset classes – probably because conventional statistical methodology is considered inadequate. (http://unstats.un.org/unsd/envAccounting/londongroup/meeting13.asp?sID=3).

that GDP is an inadequate metric to gauge well-being over time particularly in its economic, environmental, and social dimensions, some aspects of which are often referred to as sustainability." (p 8)

"We are also facing a looming environmental crisis, especially associated with global warming. Market prices are distorted by the fact that there is no charge imposed on carbon emissions; and no account is made of the cost of these emissions in standard national income accounts. Clearly, measures of economic performance that reflected these environmental costs might look markedly different from standard measures." (p 9)

Well-being is a central concept. The authors define it as having the following dimensions, which should ideally be measured simultaneously: 1 Material living standards (income, consumption and wealth); 2 Health; 3 Education; 4 Personal activities including work; 5 Political voice and governance; 6 Social connections and relationships; 7 Environment (present and future conditions); 8 Insecurity, of an economic as well as a physical nature.

In summary, the scope of the study is to cover all socio-economic and environmental aspects. T he following recommendations deal at least in part with environmental concerns:

- *Sustainability assessment requires a well-identified dashboard of indicators. The distinctive feature of the components of this dashboard should be that they are interpretable as variations of some underlying "stocks". A monetary index of sustainability has its place in such a dashboard but, under the current state of the art, it should remain essentially focused on economic aspects of sustainability.*

  At a minimum, in order to measure sustainability, what we need are indicators that inform us about the change in the quantities of the different factors that matter for future well-being. Put differently, sustainability requires the simultaneous preservation or increase in several "stocks": quantities and qualities of natural resources, and of human, social and physical capital.

  These assets should ideally be expressed in monetary values, which is difficult because of the absence of many markets on which valuation of assets could be based. Even when there are market values, there is no guarantee that they adequately reflect how the different assets matter for future well-being. This suggests starting with a more modest approach, focusing the monetary aggregation on items for which reasonable valuation techniques exist, such as physical capital, human capital and certain natural resources. In so doing, it should be possible to assess the "economic" component of sustainability, that is, whether or not countries are over-consuming their economic wealth. (p 17)

- *The environmental aspects of sustainability deserve a separate follow-up based on a well-chosen set of physical indicators. In particular there is a need for a clear indicator of our proximity to dangerous levels of environmental damage (such as association with climate change or the depletion of fishing stocks).*

  Placing a monetary value is particularly difficult for irreversible and/or discontinuous alterations to the environment. For that reason there is a need for a clear indicator of increases in atmospheric concentrations of greenhouse gases associated with proximity to dangerous levels of climate change (or levels of emissions that might reasonably be expected to lead to such concentrations in the future). Climate change caused by

> increases in greenhouse gases is also special in that it constitutes a truly global issue that cannot be measured with regard to national boundaries. Physical indicators of this kind can only be identified with the help of the scientific community. Fortunately, a good deal of work has already been undertaken in this field. (pp 18-19)

The body of the Stiglitz, Sen and Fitoussi report is organized in two sections with three identical chapter headings: 1 GDP-related issues, 2 Quality of life, and 3 Sustainable development and environment. The first section contains "a short narrative of the report contents," the second the substantial arguments that were presented (not reviewed here).

The report concludes on sustainability (p 77): "Assessing sustainability requires many assumptions and normative choices, and it is further complicated by the existence of interactions between the socio-economic and environmental models followed by the different nations. The issue is indeed complex, more complex than the already complicated issue of measuring current well-being or performance. But we shall nevertheless try to articulate a limited set of recommendations, which we shall also try to keep as pragmatic as possible." The headline recommendations follow:

1. Sustainability assessment requires a well-identified sub-dashboard of the global dashboard to be recommended by the Commission.
2. The distinctive feature of all components of this sub-dashboard should be to inform about variations of those "stocks" that underpin human well-being.
3. A monetary index of sustainability has its place in such a dashboard, but under the current state of the art, it should remain essentially focused on economic aspects of sustainability.
4. The environmental aspects of sustainability deserve a separate follow-up based on a well-chosen set of physical indicators.

In conclusion, the report represents very significant progress, reinforced by its eminent authorship, which is expected to bring the matter to the attention of larger numbers of economists, other social scientists, and scientists specializing in ecosystems and climate change. As our Appendix 5 shows, economics itself is having a serious look at its past performance and is expanding its cooperation with other disciplines, for example through the complexity theory which originated at the Santa Fe Institute in New Mexico.

But we are not yet there. Meanwhile the old GDP-dominated national accounting approach remains the basic indicator. We can qualify these measures but we cannot yet quantify their shortcomings.

### WHAT THE PUBLISHED SCENARIOS DO, AND DON'T

The SRES scenarios project emissions of carbon dioxide and other greenhouse gases. Nowhere are these projections translated into global temperature changes and other characteristics of climate change. To make the connection, future estimates from separate tables showing expected temperature increases and greenhouse gas emissions had to be correlated (Figure 2).

The closest SRES comes to a explicit recognition of the implications of climate change, as distinct from the emissions that cause it, is in Chapter 6 (summary discussion and recommendations): "The first step in the formulation of the scenarios was the review and analysis of the published literature and the development of the database with more than 400 emissions scenarios. One of the recommendations of the writing team is that IPCC or a similar international institution should maintain such a database to ensure continuity of knowledge and scientific progress in any future assessments of GHG scenarios. An equivalent database to document narrative and other qualitative scenarios would also be very useful for future climate-change assessments."

The SRES collection consists of unmitigated scenarios – they envisage worlds that might emerge in the absence of specific corrective action on climate change (the scenarios are not otherwise "policy-free"). Mitigation of climate change will of course happen in the real world; the scenarios themselves are important catalysts in this process. The troubling question is how prompt the action will be.

**Table 1: IPCC scenarios: Range of global warming estimates**

| | Estimated temperature change ($^oC$) | | | Ratio | | $CO_2$ level in |
|---|---|---|---|---|---|---|
| Scenario | Lowest (L) | Most likely (M) | Highest (H) | (H-M)/(M-L) | In logs | 2100 (ppm) |
| B1 | 1.1 | 1.8 | 2.9 | 1.57 | 0.97 | 545 |
| A1T | 1.7 | 2.4 | 3.8 | 2.00 | 1.33 | 578 |
| B2 | 1.7 | 2.4 | 3.8 | 2.00 | 1.33 | 616 |
| A1B | 1.7 | 2.8 | 4.4 | 1.45 | 0.91 | 710 |
| A2 | 2.0 | 3.4 | 5.4 | 1.43 | 0.87 | 846 |
| A1FI | 2.4 | 4.0 | 6.4 | 1.50 | 0.92 | 964 |

Notes:

Estimates are from various sources including many Atmosphere-Ocean General Circulation Models (AOGCMs). They do not include deterioration of climate change prospects after IPCC 2007 was finalized. The estimates are therefore conservative.

Temperature changes are expressed as the increase from 1980-1999 to 2090-99. To express the change relative to the period 1850-1899 add 0.5%.

The $CO_2$ forcing in 2100 is the average reference case for two models: ISAM and Bern-CC (IPCC 2001 WG1 report, Appendix II: SRES tables).

Source: IPCC 2007 Synthesis Report, Table 3.1.

The projections of temperature change are loaded with uncertainties in the carbon cycle and in the response of the climate to a given increase in atmospheric greenhouse gases. A worst-case scenario may turn out better than the median estimates suggest, and a best-case scenario may result in temperature increases exceeding risky levels. This appendix draws attention to such uncertainties.

Climate change has become a progressively more urgent issue during the past decade, due largely to the impact of positive feedback effects exceeding expectations (such as the melting of sea-ice and the impact on the Greenland ice sheet). Some scientists find it difficult to imagine how we can enter a world where average global temperatures have risen three or four degrees or more and still charge ahead at the predicted rates of growth. NASA's James Hansen warns that unless we limit the atmospheric greenhouse gas content to current levels or even below, we may trigger major events that will make the Earth a very difficult place to live (Hansen et al. 2008). Quoting from the abstract of the paper: “If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that $CO_2$ will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that.”

Using probabilistic analysis, Meinshausen et al. (2009) find that if global greenhouse gas emissions grow to more than 25% above 2000 levels in 2020, the probability of exceeding a $2^{O}$C rise by 2100 rises to between 53% and 87%. Even halving emissions by 2050 carries a probability of between 12% and 45% of exceeding $2^{O}$C. The authors note that more than 100 countries have adopted a global warming limit of $2^{O}$C or below, relative to pre-industrial levels, as a guiding principle for mitigating climate change risks, impacts and damages. “Given the substantial recent increase in fossil $CO_2$ emissions (20% between 2000 and 2006 [as reported by Canadell et al. 2007]), policies to reduce global emissions are needed urgently if the below $2^{O}$C target is to remain achievable.” (Meinshausen et al. 2009, p 1160).

Science journalists Mark Lynas (2008) and Gaia Vince (2009) describe nightmarish “above-4-degree” worlds based on persuasive scientific findings. So does Clive Hamilton (2010) based on a conference of 140 climate scientists and others that he attended (and contributed to) in Oxford in September 2009, named "4 degrees and beyond: Implications of a global change of 4+ degrees for people, ecosystems and the earth system."[46]

Prominent Stanford University environmental scientist Stephen Schneider points to the low but significant probability that the $CO_2$-equivalent level will reach 1,000 ppm, which adjusted for other greenhouse gases was the level predicted in 2001 in the worst-case IPPC scenario, A1FI (see Table 1). He writes: “An atmosphere in 2100 with 1,000 parts per million of carbon-dioxide equivalent would be catastrophic. To understand the effect of this, we need to peer into what Harvard University economist Marty Weitzman calls the “fat tail” of the probability distribution for climate damage. Although the likelihood is uncertain — and probably low[47] — we should give these events more attention because not doing so could be potentially disastrous.” (Schneider 2009)

Weitzman (2009a) has done fundamental research into what has become known as the *fat tail* of the probability distribution – that is, a modification of the kurtosis of the standard bell curve or normal distribution. A high kurtosis means a low, relatively even distribution with more extreme observations (the fat tail), whereas a low kurtosis portrays a chart with skinny tails and a distribution concentrated towards the mean. In another paper (2009b) Weitzman explains:

“The probability of a disastrous collapse of planetary welfare from too much $CO_2$ is non-negligible, even if this low probability is not objectively knowable.” (p 1)

[46] A 204-page abstract book of the conference (http://www.eci.ox.ac.uk/4degrees/downloads/abstractbook.pdf) starts with the keynote address by Professor Hans Joachim Schellnhuber of the Potsdam Institute for Climate Impact Research. Hamilton’s contribution, with Tim Kasser, was on adaptive coping strategies in a $4^{O}$C world.

[47] The *Synthesis Report* from the science conference on climate change in Copenhagen in March 2009 takes a stronger view. Its “Key Message 1” is that greenhouse gas emissions and other indicators of climate change are changing near the upper boundary of the IPCC range of projections (Richardson et al. 2009, p 6).

"A key starting point for any CBA of climate change should recognize that future temperatures or damages cannot be known exactly and must be expressed as a probability density function (PDF). Yet, most existing IAMs treat central forecasts of temperatures or damages as if they were certain and then do some sensitivity analysis on parameter values. In the rare cases where an IAM formally incorporates uncertainty, it typically uses thin-tailed PDFs including, especially, truncation of PDFs at arbitrary cutoffs. … I will argue that the PDF of distant-future temperature changes is fat tailed. A thin-tailed PDF assigns a relatively much lower probability to rare events in the extreme tails than does a fat-tailed PDF." (p 2)

"Fat-tailed CBA has strong implications that have neither been recognized in the literature nor incorporated into formal CBA modeling of disasters like climate-change catastrophes." (p 3)[48]

Weitzman's analytic focus differs from most other economists' concerns. The economic debate on the IPCC scenarios has been largely along two interrelated lines. One concern is the use of market exchange rates (MER) to compare standards of living from country to country, rather than purchasing power parity (PPP), where the conversion factor shows how much of a country's currency is needed in that country to buy what $1 would buy in the United States. There is generally less difference between apparent living standards using PPP, so in general terms the poorer nations have less catching up to do (though still a lot) in the A1 scenario.

The economists' second concern relates to IPCC's method of building up the global projections from four massive aggregates of national statistics: 'OECD 90' (the members in 1990), REF (Eastern Europe and the former Soviet Union), ASIA (developing Asian countries), and ALM (developing countries in Africa, Latin America, and the Middle East). The criticism has considerable validity, not followed up in this appendix. McKibbin et al. (2004) advocate a multi-sector, multi-country, inter-temporal comparison base as a superior solution.

This appendix has a different purpose. Economists have made little or no attempt to quantify the impact of global warming and other aspects of climate change on GDP across the range of the IPCC scenarios. However, Appendix 3 showed three of the most prominent contributors to the economics of climate change and poverty agreeing that a (BAU) scenario would have dismal consequences for the world economy: Stern (2006), Garnaut (2008), and Sachs (2008). According to the IPCC no SRES scenarios should be interpreted as BAU, but many scientists put that label on the global economics-driven fossil-energy intensive A1FI scenario. This is incorrect because the whole idea of scenario *planning* is to establish a framework of alternative equally credible futures, but late 20$^{th}$ century economic policies were admittedly highly growth-driven, increasingly globalized, based on fossil energy, and influenced by powerful lobby groups.

Chapter 2 of the recent book by Nicholas Stern on the economics of climate change (2009) is called *The dangers.* A table on page 26 shows that if the stabilization level is 450 ppm $CO_2$-e (counting all greenhouse gases and not just $CO_2$) there is a 78% chance of exceeding 2$^{O}$C, and 18% chance of exceeding 3$^{O}$C, after which the percentages reduce drastically (3% chance of exceeding 4$^{O}$C). But at a stabilization level of 750 ppm $CO_2$-e the chance of exceeding 2$^{O}$C is

[48] CBA stands for cost-benefit analysis and IAM for integrated assessment model.

100%, that of exceeding $3^OC$ 99%, $4^OC$ 82%, $5^OC$ 47%, $6^OC$ 22%, and $7^OC$ 9%. These estimates, incidentally, are in excess of the probabilistic data in this paper, which are from IPCC's Fourth Assessment Report in 2007.

Some of Stern's comments follow: "If we do not act responsibly, it is likely that by the end of this century or sometime in the first half of the next century, we will see temperature increases of $4\text{-}5^OC$ or higher relative to 1850. It is very difficult to describe such a world; the science has much less to go on. But it would, in all likelihood, be a radical transformation of the world we know." (pp 30-31)

"Some areas, probably much of Southern Europe, might become deserts. Most of Florida and Bangladesh would eventually be submerged. Of great importance here is that the pace at which temperature changes occur would be extraordinarily rapid in relation to historical and evolutionary time. Increases of the scale of $5^OC$ could happen, indeed are likely to happen, within the space of a century or two if we do not act." (p 31)

"The point is that with temperature changes of this magnitude, the physical geography is rewritten. If the physical geography is rewritten then so too is the human geography of the world. There would be movement of people on an immense scale. The lessons of the last few hundred years surely tell us that the movements of billions of people in a fairly short period of time would plunge the world into massive and extended conflict." (p 31)

Stern is a world leader in climate change economics. Aided by Garnaut's and Sachs's and his own previous assessments of the adverse consequences of BAU, his comments remove some of the unease this writer has felt seeing that most warnings come from the world of science, while his fellow economists apparently steer away from quantifying the possible economic consequences of a $4^O$, $5^O$ of $6^O$ world in favor of tackling technical matters like MER versus PPP and the extent to which the global economic scenario model should be disaggregated. These matters are of course also very important.

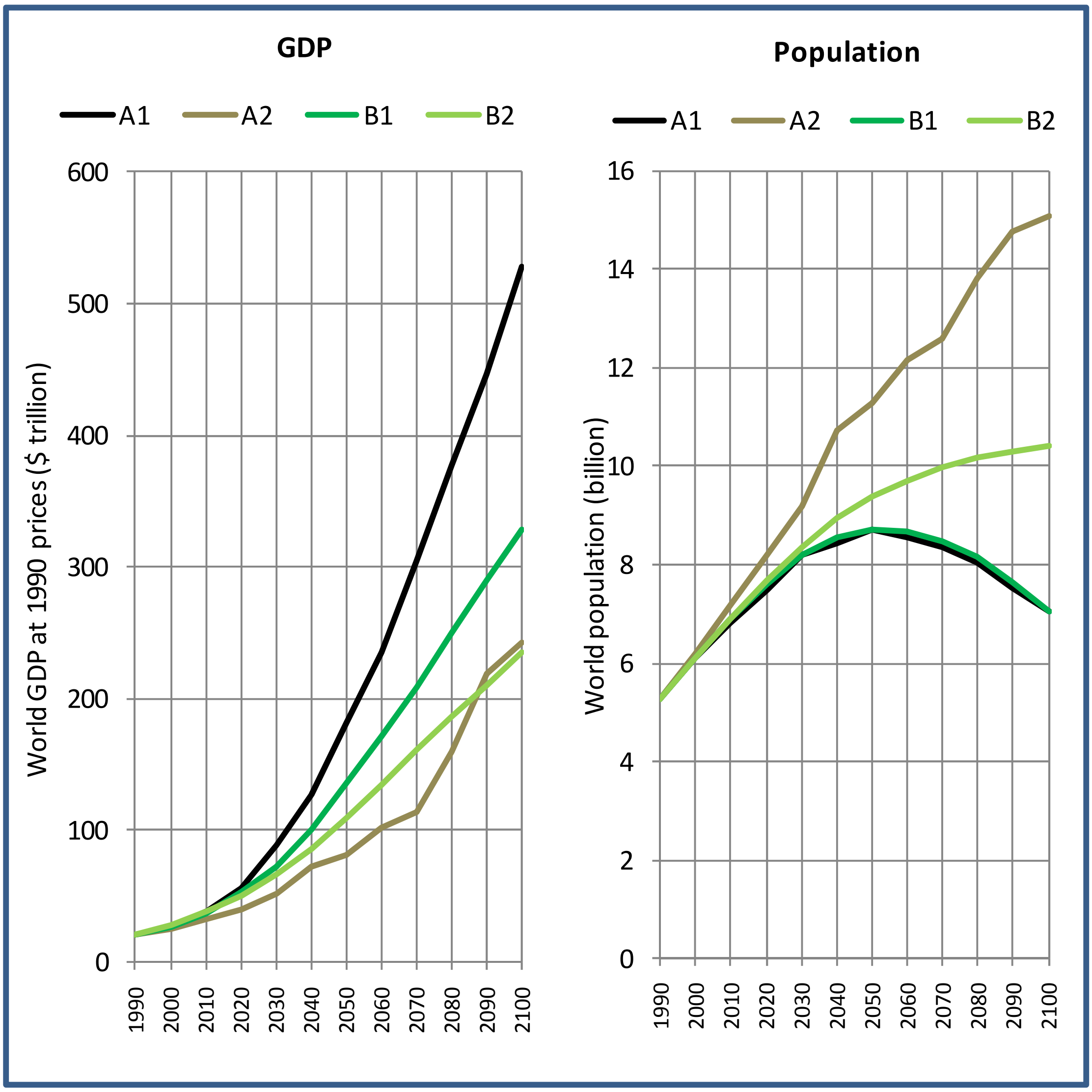
Before presenting the analysis that follows, a disclaimer is needed. To all intents and purposes, this appendix is based on adequate, reasonably readily available data. It could be refined in many ways, given much more time and better and more complete national and regional statistics. Its main focus is on the connection between the quantitative IPCC scenarios and the estimated impact of living in a world where the *average global temperature* has risen by one, two, three, four, five, or six degrees Celsius. What the more extreme increases would mean for particular geographic regions must be, for now, left mainly to the imagination.

## THE IPCC SCENARIOS

Table 1 showed the range of temperature estimates associated with each scenario. Three variations of A1 depict worlds of globally interconnected economic growth: fossil-energy dominated (A1FI), balanced use of fossil and renewable energy (A1B), and renewables (probably supplemented by nuclear energy) as the principal energy source (A1T). A2 is also driven by economics but globalization is no longer a strong force. Environmental considerations are more important in the two "B" scenarios, with B1 depicting a globalized world and B2 a regionalized world. [49]

The scenarios were devised between 1997 and 2000 for the SRES report (from data relating to the early 1990s), but most of the information in Table 1 was derived from the Fourth Assessment Report in 2007. In addition to the "most likely" estimates, our analysis uses the extreme high and low observations to indicate the possible ranges under each scenario.

**Figure 1: Global IPCC 2001 projections**




An attempt was made to estimate the probability distributions between the extremes, but there is insufficient published information. It would be interesting to find out whether one or both of the tails of the distribution are "fat" as suggested by Weitzman. The table shows a longer tail towards the upper boundary, indicated by a ratio between the upper and lower intervals averaging a little below 1.5 for four of the six scenarios. The exceptions are the

[49] The final analysis of scenario stories in Chapter 6 suggests that B2, if written today, would be more favorably judged. The B2 estimates in this appendix, however, are based on the original SRES scenario from 2000.

regionalized environmental scenario B2 and A1T, the renewable energy driven growth case. We shall see below that these two scenarios are a little out of line with the remaining four, when compared with cumulative $CO_2$ emissions to 2100.

Transforming the three estimated temperature changes to logarithms, as shown in the second buff-colored column of Table 1, suggests that the distributions may be closer to log-normal rather than normal: the ratio of the transformed upper to lower intervals is between 0.87 and 0.97 for the four scenarios, compared with a range from 1.43 and 1.57 for the untransformed data. This still doesn't tell us whether the tails are fat – though perhaps the distribution hints that the upper tail may be.

**Table 2: Annual rates of change: main 2001 projections (10-year averages)**

| | Scenario A1 | | | Scenario A2 | | |
|---|---|---|---|---|---|---|
| | Population | GDP | GDP/head | Population | GDP | GDP/head |
| 1990 | | | | | | |
| 2000 | 1.52% | 2.50% | 0.97% | 1.57% | 2.31% | 0.73% |
| 2010 | 1.07% | 3.55% | 2.46% | 1.54% | 2.38% | 0.83% |
| 2020 | 0.97% | 4.07% | 3.07% | 1.33% | 2.41% | 1.06% |
| 2030 | 0.88% | 4.66% | 3.74% | 1.12% | 2.36% | 1.23% |
| 2040 | 0.31% | 3.62% | 3.30% | 1.57% | 3.52% | 1.92% |
| 2050 | 0.31% | 3.62% | 3.30% | 0.53% | 1.21% | 0.68% |
| 2060 | -0.19% | 2.63% | 2.83% | 0.72% | 2.25% | 1.52% |
| 2070 | -0.19% | 2.63% | 2.83% | 0.36% | 1.14% | 0.77% |
| 2080 | -0.42% | 2.16% | 2.59% | 0.94% | 3.40% | 2.43% |
| 2090 | -0.64% | 1.70% | 2.36% | 0.64% | 3.20% | 2.54% |
| 2100 | -0.64% | 1.70% | 2.36% | 0.22% | 1.07% | 0.85% |
| | **Scenario B1** | | | **Scenario B2** | | |
| | Population | GDP | GDP/head | Population | GDP | GDP/head |
| 1990 | | | | | | |
| 2000 | 1.49% | 2.48% | 0.97% | 1.47% | 3.08% | 1.58% |
| 2010 | 1.19% | 3.38% | 2.16% | 1.24% | 3.15% | 1.89% |
| 2020 | 1.01% | 3.48% | 2.45% | 1.08% | 2.76% | 1.67% |
| 2030 | 0.73% | 3.35% | 2.60% | 0.88% | 2.67% | 1.78% |
| 2040 | 0.42% | 3.26% | 2.83% | 0.65% | 2.62% | 1.96% |
| 2050 | 0.19% | 3.02% | 2.82% | 0.48% | 2.50% | 2.02% |
| 2060 | -0.04% | 2.39% | 2.43% | 0.35% | 2.10% | 1.74% |
| 2070 | -0.22% | 1.96% | 2.18% | 0.26% | 1.82% | 1.56% |
| 2080 | -0.41% | 1.82% | 2.24% | 0.20% | 1.44% | 1.24% |
| 2090 | -0.60% | 1.51% | 2.13% | 0.14% | 1.22% | 1.07% |
| 2100 | -0.83% | 1.25% | 2.10% | 0.10% | 1.11% | 1.01% |

Source: http://sres.ciesin.org/final_data.html (Excel version)

The statistics on $CO_2$ abundance in Table 1 are from the 2001 Third Assessment Report and would almost certainly be higher if calculated today. The numbers also exclude other greenhouse gases such as methane and nitrous oxide, and soot. The evidence (including Stern's probability table quoted in the introduction) is that prospects have deteriorated further since the temperature ranges were calculated for the Fourth Assessment Report in

2007, and that could have an influence on the policies directed towards non-$CO_2$ greenhouse gases.

The four scenarios display very different projections of GDP and population (Figure 1). Economic growth unrestrained by warming is highest in A1 (all three variants), second-highest in the globally and environmentally orientated scenario B1, and lowest in the regionally divided A2 and B2 scenarios. The two globally orientated scenarios show similar population patterns over the century, reaching a maximum of about 8.7 billion in 2050 and falling thereafter. The regionalized scenarios show continuous population growth, A2 to over 15 billion by 2100, B2 to over 10 billion. Such increases in the global population would in itself have potential impacts on economic growth, which may not have been taken adequately into account in the SRES projections.

The assumptions behind the four GDP and population projections (Table 2) are also queried. The high-growth A1 scenario shows an acceleration in economic growth to 4.7% pa in the 2020s, and even at the end of the century, when population has been falling for decades, total GDP is assumed to grow by 1.7% pa.  The annual average for the period from 1990 to 2100 is 3.0%.  GDP per capita is assumed to slow down from 3.8% pa in the 2020s to a still substantial 2.4% between 2080 and 2100.

Scenario A2 shows somewhat erratic growth patterns through the century, which were retained when the revised projections shown in Table 2 were published. The average for the full period is 2.3% pa, second-lowest of the four main scenarios.

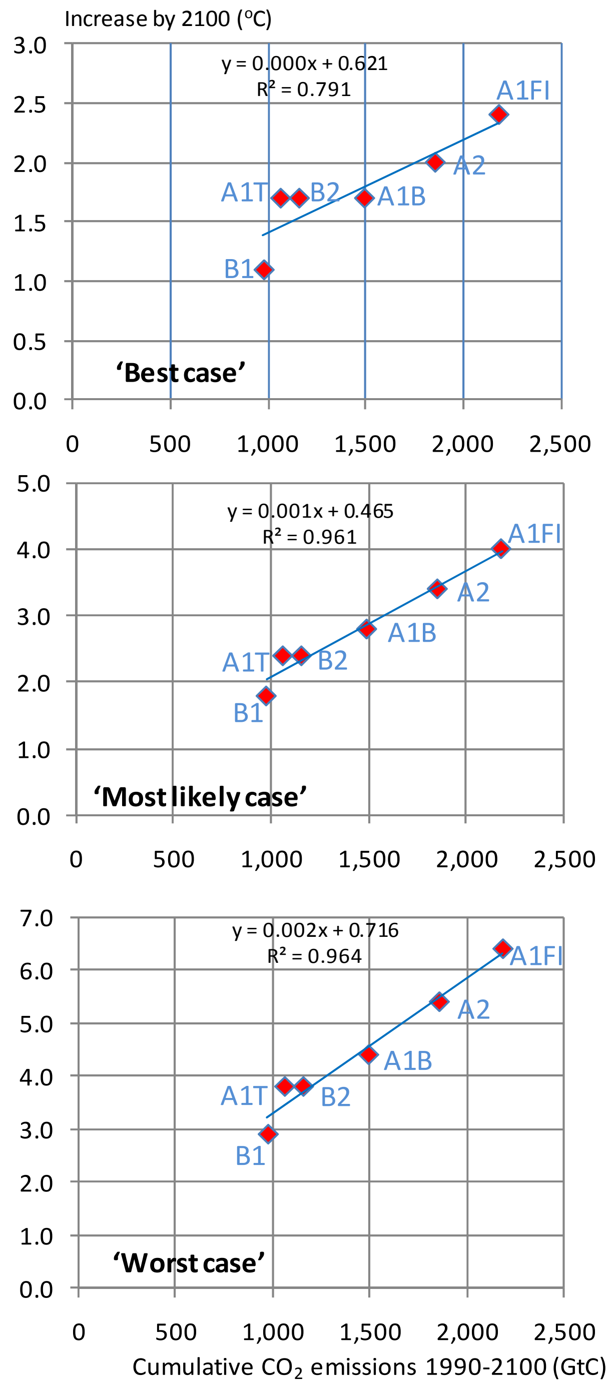
Of the two more environmentally aware scenarios, the globally geared B1 shows GDP growth in excess of 3% pa through the first half of the century, before the rate reduces towards 1.25% in the last decade (average 1990-2100 2.5% pa). Population growth and decline is similar to A1, so GDP per head is more regular, peaking at 2.8% pa in the 2030s and 2040s and maintaining a rate of over 2% in 2090-2100. The regionalized environmentally

**Table 3: Cumulative CO2 emissions since 1990 (GtC)**

| Year | A1FI | A2 | A1B | B2 | A1T | B1 |
|---|---|---|---|---|---|---|
| 1990 | - | - | - | - | - | - |
| 2000 | 75 | 75 | 75 | 75 | 75 | 75 |
| 2010 | 164 | 163 | 170 | 159 | 162 | 162 |
| 2020 | 276 | 272 | 287 | 248 | 260 | 261 |
| 2030 | 421 | 407 | 423 | 343 | 373 | 370 |
| 2040 | 602 | 561 | 572 | 446 | 499 | 484 |
| 2050 | 821 | 729 | 731 | 554 | 623 | 599 |
| 2060 | 1,069 | 912 | 892 | 667 | 741 | 704 |
| 2070 | 1,334 | 1,112 | 1,051 | 783 | 848 | 794 |
| 2080 | 1,614 | 1,332 | 1,206 | 901 | 937 | 868 |
| 2090 | 1,899 | 1,579 | 1,353 | 1,026 | 1,008 | 928 |
| 2100 | 2,182 | 1,855 | 1,492 | 1,157 | 1,061 | 976 |

Source: http://sres.ciesin.org/final_data.html orientated B2 shows lower growth, the rate decreasing to just over 1% pa by the 2090s. The annual average for the full period is 2.2%, the lowest growth rate among the four scenarios. The growth prospects are consequently much lower in the regionalized scenarios than the globalized ones, and since these scenarios have much higher population growth, the gap in per-capita GDP is even higher.

**Figure 2: Cumulative emissions and global temperature rise**




Source: See Tables A2.1 and A2.3

## SRES SCENARIOS LINK WITH GLOBAL WARMING PROJECTIONS

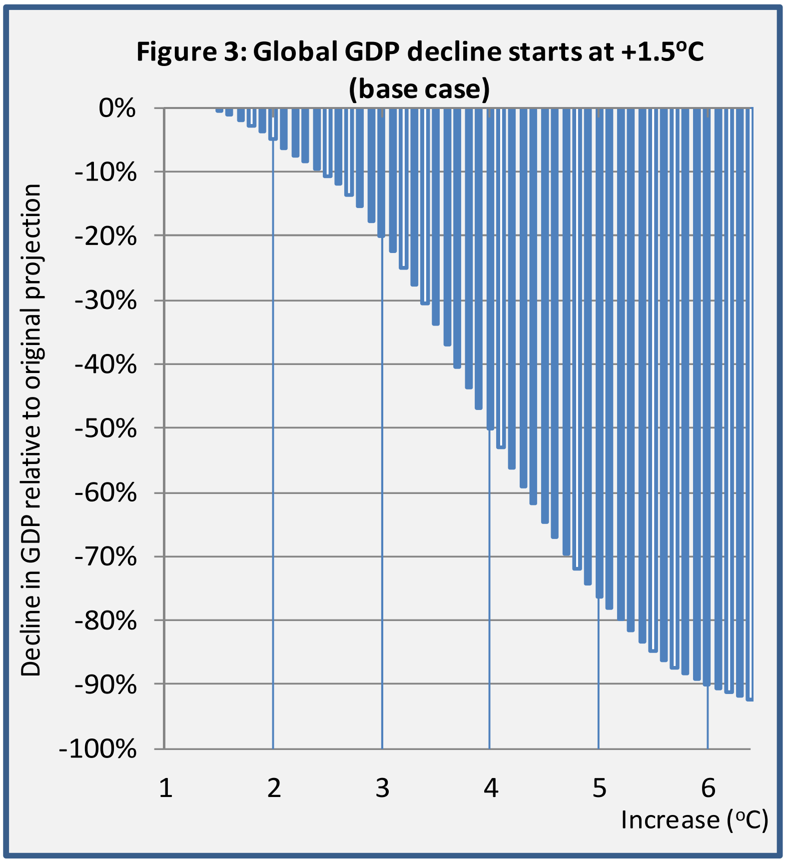
One problem in setting up this research was the lack of a direct link between economic growth and the global average temperature through the 21st century. The final quantitative analysis is shown for all 40 A1, A2, B1 and B2 SRES scenarios (from which IPCC selected the six marker and variant scenarios discussed in this appendix) in the source shown below Table 3.

The quantitative projections contain a great deal of detail in addition to GDP and population, relating to final and primary energy use, cumulative use of coal, oil and gas resources, land use, and standardized anthropogenic emissions. They also, importantly for our purposes, show cumulative $CO_2$ emissions per decade from 1990 to 2100 (Table 3). These emissions are shown in order of size in 2100, from 2,182 gigatons of carbon for the fossil-intensive A1FI scenario to under 1,000 GtC for B1. The emissions vary enormously between the three A1 scenarios with the renewables-driven variant not much higher than B1.

It remains to test the statistical relationship between cumulative $CO_2$ emissions and the estimated increase in global average temperature by 2100. This involved setting up a “best”, “most likely” and “worst” case for each of the six scenario variants. The best case is the lowest temperature change along the ranges shown in Table 1, the most likely case is as shown in Table 1, and the worst case the highest temperature change along the ranges. The scatter diagrams in Figure 2 show how the level of cumulative $CO_2$ emissions in 2100 shown in Table 3 correlate with the estimated temperature increase over the century in the three cases. The plots show that there is a clear connection.

In the best case, the unconstrained temperature increase for scenario B1 is 1.1°C, and for three scenarios, A1T, B2, and A1B, all 1.7°C. The highest readings relate to the regionalized economic scenario A2 (+2.0°C), and the fossil-fuel-dominated A1FI (+2.4°C). This does not yield a particularly high correlation between cumulative emissions and the global temperature rise, mainly because of the lack of differentiation between A1T, B2 and A1B. At these relatively small changes, the clearest signs of differentiation are the higher increases in temperature for the regionalized economic growth scenario (A2) and the fossil-fuel global growth scenario (A1FI).

The differentiation becomes clearer in the ‘most likely’ case, where the only real deviations from the regression line are A1T (a fraction of a degree warmer than might be expected) and B1 (one-fifth of a degree lower). The picture is similar in the extreme upper case, designated “worst”. The correlation between the cumulative emissions and the expected global temperature increase between the late 20th century and 2100 is high ($R^2$ is over .96 for both the most likely and the worst case).



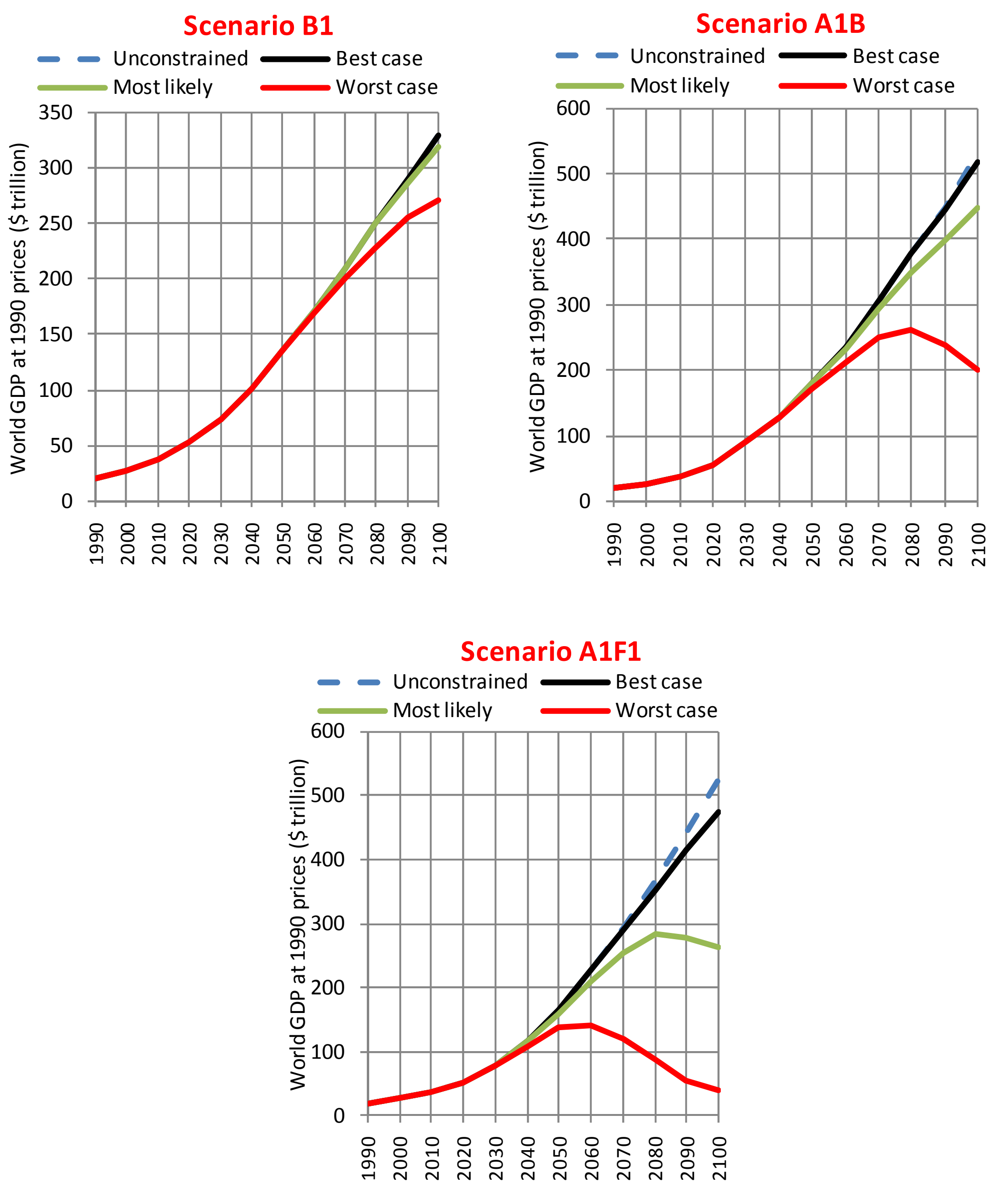

## WHAT IS THE IMPACT OF WARMING ON GDP?

These assumptions need careful debate; all we can do in an explorative review is to postulate some impacts (from Figure 3):

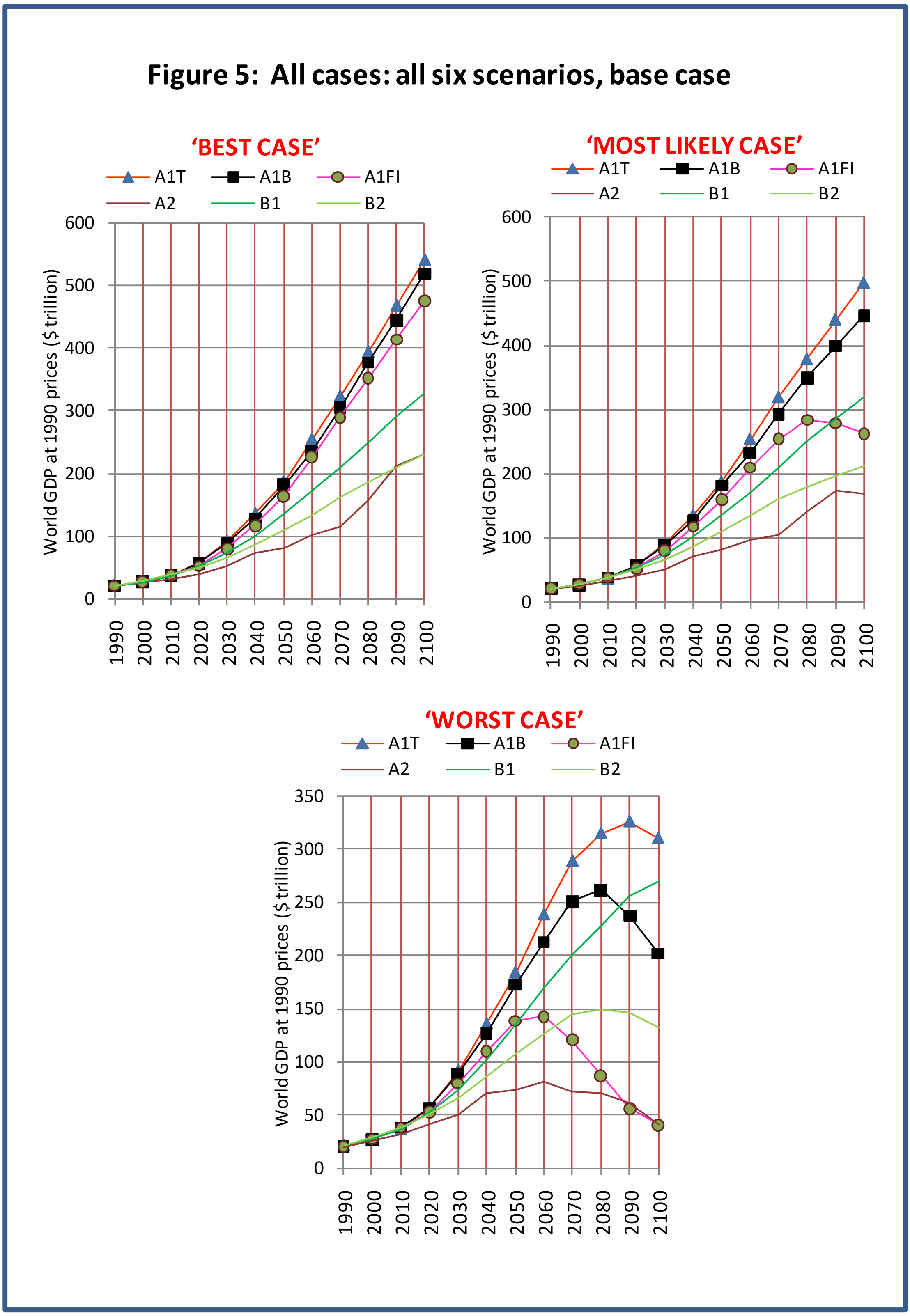
An increase of 2°C is now seen by many as a limit beyond which the world should not move. The assumption in Figure 3 is that when 2°C is reached, GDP has lost 5% compared with the original projections. The impact of warming starts to kick in at +1.5°C.

At the other end of the range, from say 5°C up, economies around the world may be largely ruined, according to the scientific opinions collected by Lynas and others, and the qualitative assessment by Stern and others. These levels are not sacrosanct but the judgment is that the reduction could be severe. James Lovelock would endorse that. The final paragraph in *The Revenge of Gaia* (Lovelock 2006) begins: "Meanwhile in the hot arid world survivors gather for the new Arctic centers of civilization; I see them in the desert as the dawn breaks and the sun throws its piercing gaze across the horizon at the camp. … Their camel wakes, blinks and slowly rises on her haunches. The few remaining members of the tribe mount. She belches,

**Figure 4: Global GDP, three selected scenarios, base case**



and sets off on the long unbearably hot journey to the next oasis." (p 159) Gaia has had her revenge.




How the graph develops between these extremes is unknown. It is assumed in the base case represented by Figure 3 that 20% of GDP may have been lost at $3^0$C, 50% by $4^0$C, a little over 75% by $5^o$C, and 90% by $6^o$C. Smaller reductions relative to the unconstrained IPCC projections may be possible, but would merely change the scale and timing, not the substance (refer the first variant of the base case below). It may also be argued that the reductions would be less severe at lower temperature changes but would kick in more strongly, say, from +3°C or +4°C – the second variant case shown below. The shape of the curve in Figure 3 and subsequent graphs showing the variants is not sacrosanct, only a first approximation.

As previously noted, all these cases assume that a given scenario is allowed to play out without action to mitigate the events. This is the usual assumption behind the IPCC scenarios developed to date, and therefore also here.

## BASE CASE RESULTS

Figure 4 compares three of the scenarios, B1, A1B (the balanced-technology strong global growth scenario), and A1FI, where fossil fuels continue to reign supreme. The three cases compared are the best case (lowest growth in warming under a given $CO_2$ regime in Table 1), the 'most likely' case; and the worst case, again according to Table 1. The partly or fully hidden "unconstrained" dotted line on the charts is the original SRES projection.

Figure 5 compares all six scenarios (including the three variants of A1). In the best case which may not occur, especially if the tail in the distribution towards higher temperature changes is the longer and fatter one, the three A1 scenarios are way ahead of the others. In the "most likely" case, A1FI turns down from 2080 and is exceeded by the environmentally orientated B1 in the final decade of the century. In the worst case scenario, A1FI collapses after 2050 and all GDP measures start to decline between 2050 and 2090 except B1 that continues to grow and by 2100 is second to only A1T, the renewable technology high-growth orientated scenario. The green B1 line on Figure 5 highlights that this scenario retains its original unconstrained level and growth much better than the other scenarios.

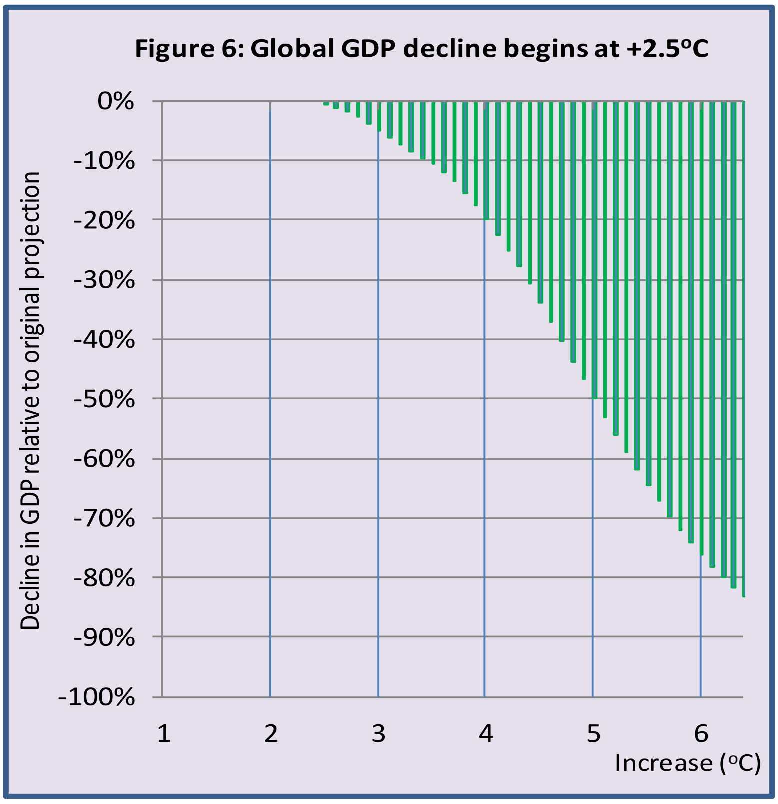
Despite the importance of renewable energy sources in the economics-driven A1T scenario, it too reaches a limit of growth in our base case while the environmentally friendly global B1 scenario doesn't within the time set. All this is based on the probability distributions in Table 1, which were developed by the IPCC. Subsequent evidence suggests that these distributions remain largely current for the best case (B1) but the worst cases – A1FI in particular – are getting worse (Pearce 2009).

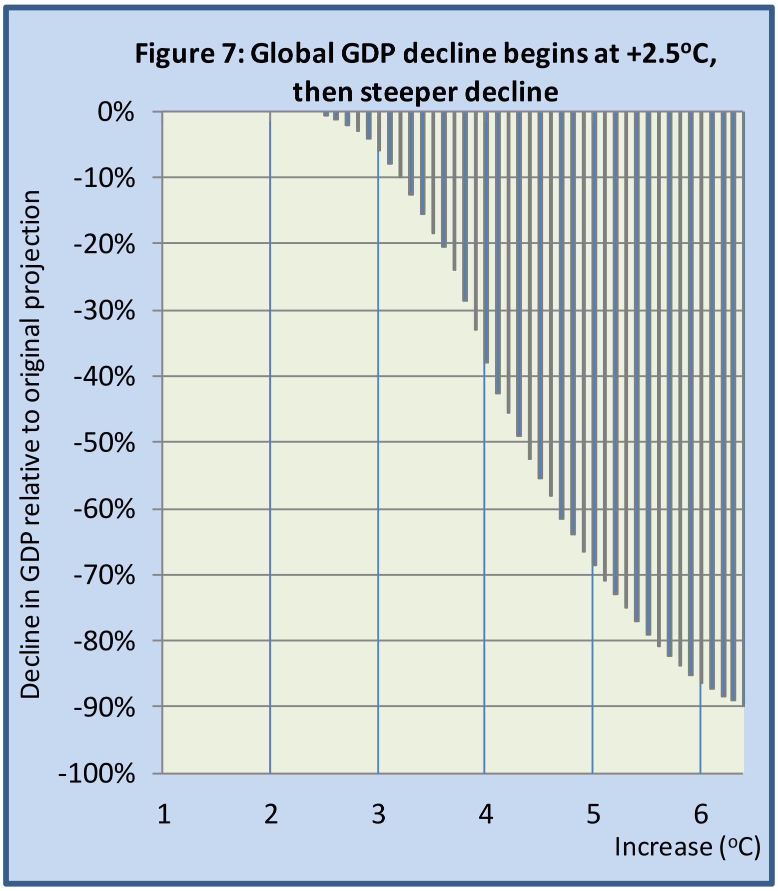
These conclusions depend on the assumption on how much global GDP will be affected by particular increases in warming (based on Figure 3). There are plenty of other factors to take into account, including patterns of warming across the planet, how warming interacts with other climate change variables such as sea-level rise, ocean acidification, droughts and floods, regional weather patterns such as monsoons and hurricane activity, and how much adaptation is possible not just for the big end of town but for all people in all countries.

## ALTERNATIVE ASSUMPTIONS

The remainder of this appendix presents two alternatives to the base case. The first alternative postpones the onset of reduced economic growth due to climate change from

+1.5°C to +2.5°C (Figure 6). The shape of the curve is otherwise unchanged from the base case in Figure 3.

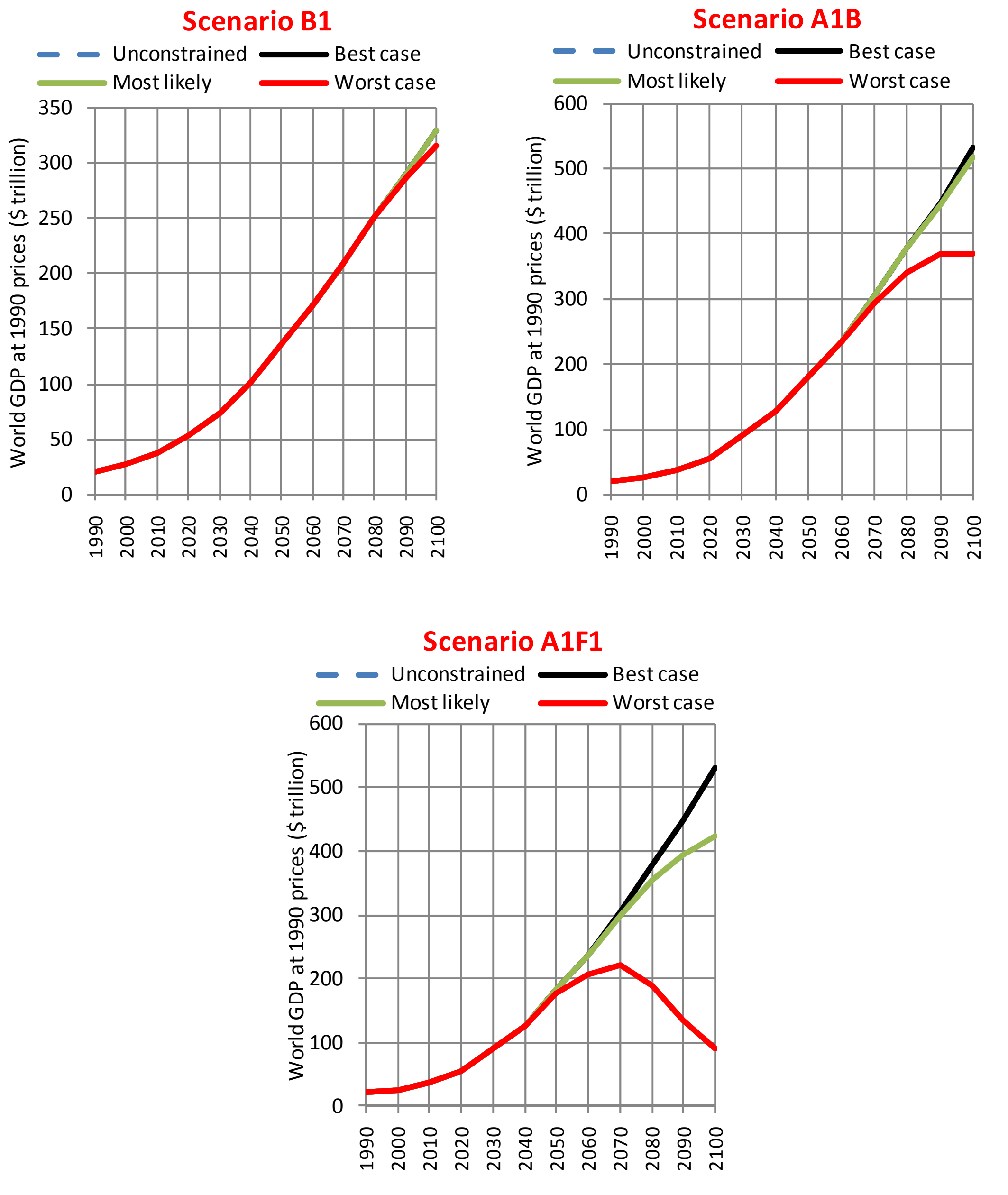



In the second variant, economic growth is again assumed to be unaffected by global other climate change impacts until the average global warming gets to 2.5°C above preindustrial levels. However, it then plunges more heavily than in the two other cases towards a 90% reduction in global GDP by 2100 (Figure 7).

In the more benign case, the three chosen scenarios are naturally least affected by the economic assumptions (Figure 8). The global environmental B1 scenario is only marginally affected even in the worst case. The global economic middle-of-the-road scenario A1B is also fairly unaffected except in the worst case, where economic growth is curbed in the last decade of the 21st century. The fossil fuel scenario A1FI, however, is reduced by 20% ($100 trillion) by 2100 in the most likely case, and collapses from 2070 in the worst case. And that is the most benign of our three variant cases and possibly too optimistic.

**Figure 8: Global GDP when decline starts at 2.5°C**

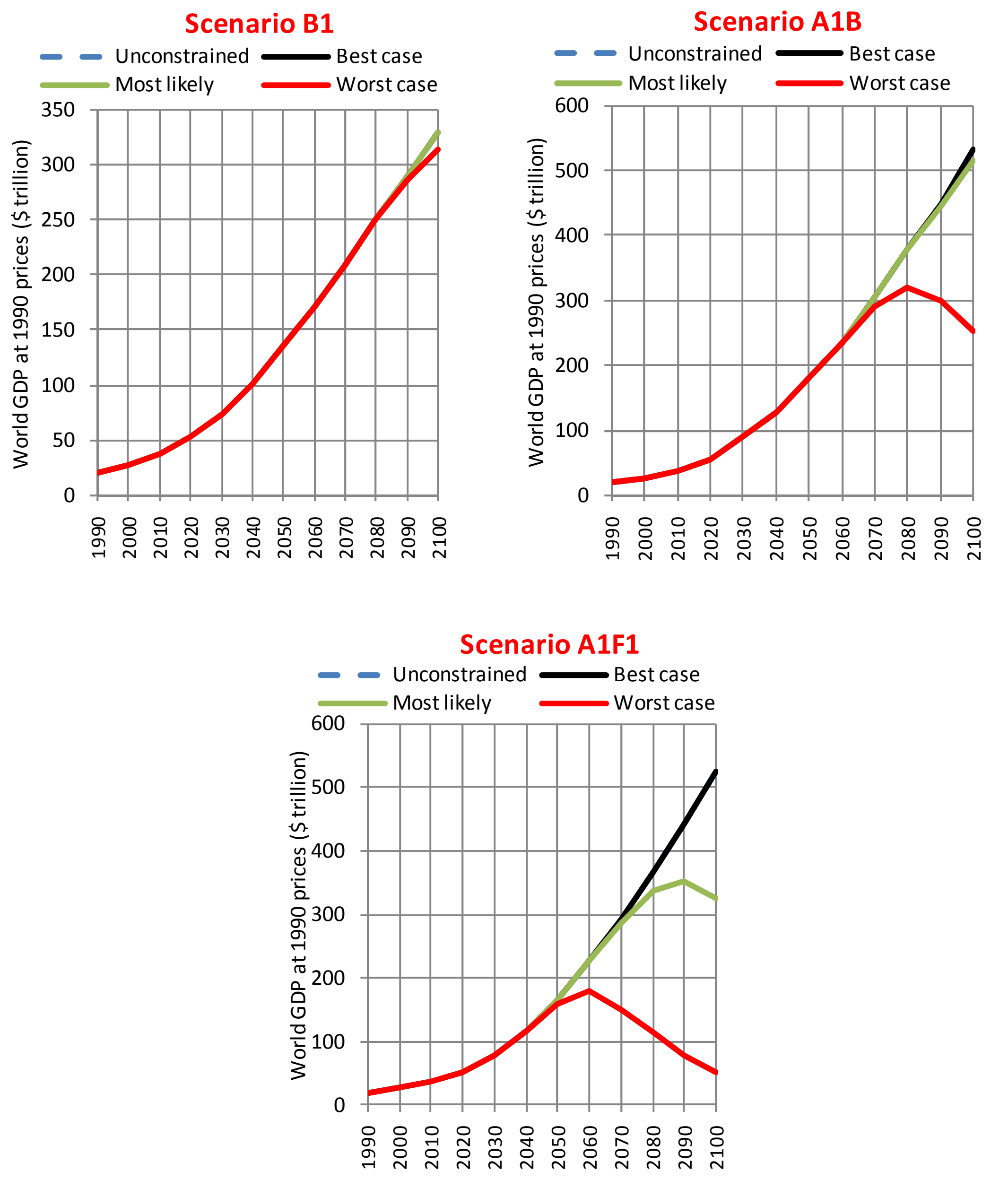



The first result in the third case, where the impact on the global economy starts at +2..5$^{O}$C but then has greater impact than the first two cases (Figure 9) is that the environmentally benign global scenario B1 is again only marginally affected by the assumptions and only in the worst case. In the two other cases, B1 continues its path towards a global world product of some $330 trillion by the end of the century.

The “balanced” global growth scenario A1B is projected to suffer economic collapse in the late 21st century as the worst case, while it will be largely unscathed in the best and most likely cases (growing towards a world product of more than $500 trillion).

If the world insists on continuing to favor fossil fuels, economies starting to collapse are indicated from about 2090 in the most likely case, and from 2060 in the worst case. Only in the best case would it be favored to show economic growth to the end of the 21st century. This is similar though slightly less severe than the base case presented in Figure 4.

**Figure 9: Global GDP when impact first delayed, then steeper**




In summary, postponing the impact of rising temperatures until +2.5$^{O}$C is reached, but then assuming a more precipitate collapse as the Earth moves into climates governed by +4$^{O}$C or more, initially makes these assumptions look relatively benign but the growth-based economic scenarios begin to take on a nightmare character in the second part of the century. It reinforces the need, already suggested by the base case, to move to an environmentally friendlier world like the one represented by the B1 scenario.

These assumptions can of course be varied in many ways. Have we been too severe in postulating gross world product declines of 90% or more when the global average temperature increases to 6$^{O}$C or more? One final check was to assume an arithmetically constant decline of 1.875% for each tenth of degree increase from +2.5$^{O}$C to the maximum +6.4$^{O}$C, reaching a total 75% decline at that temperature. Concentrating on the worst case only, there is little change to the B1 scenario, while the marker A1B scenario starts to slow down from 2070 ($276 trillion) to reach $307 trillion in 2080, $322 trillion in 2090, and $332 trillion in 2100. This is still higher than the B1 level for that year ($298 trillion), but the margin is clearly reducing between the two.

The fossil-intensive scenario A1FI now peaks in 2070 at $189 trillion, declines marginally to $188 trillion by 2080, after which the decline gathers speed: $168 trillion in 2090 and $131 trillion in 2100. So within a wide range of assumptions about the connection between global warming and the gross world product, the worst case remains that the unmitigated fossil-intensive scenario spells economic collapse towards the end of this century.

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# APPENDIX 5: THE CHANGING ECONOMIC PARADIGM

## INTRODUCTION

Greenhouse gas emissions constitute the greatest market failure the world has seen (Stern 2006, p 1; Stern 2009, pp 11-13). This is an important reason why the macroeconomic policy model that guided the United States, Great Britain and other economies over thirty years is being reappraised. The neoclassical economic policy philosophy that became prominent in the 1970s asserted that free markets are self-regulating and governments need not interfere with businesses pursuing their own self-interest. This philosophy is being critically questioned as climate change starts to bite, because it allows major polluting industries to operate without proper environmental control.

Dealing with climate change became progressively more urgent with the mounting evidence that previous climate projections which showed regular and steady rises in emissions did not tell the full story. From 2000 onwards (Cox et al. 2000)[50] climate models have contained *positive feedback loops* incorporating events that can trigger potentially catastrophic change in the global climate – events that have already become visible such as the melting sea-ice, ice caps and thawing permafrost in the Arctic.

There are many references in the recent literature to worst-case scenarios of only a few years ago being exceeded, none more authoritative than NASA's James Hansen and his colleagues (Hansen et al. 2008 is a good example). Hansen only fairly recently criticized his fellow scientists for being reticent when evidence still had a tiny element of uncertainty (Hansen 2007); however, there was no reticence in the synthesis report from the climate change conference of scientists in Copenhagen, Denmark, in March 2009 (Richardson et al. 2009). Its six key messages are stark, uncompromising, and call for urgent action.

The book *Six Degrees* by Mark Lynas (2008) provides a well-researched, readable, and frightening overview of what a warming world might mean to humankind. A recent Australian book (Spratt and Sutton, *Climate Code Red*, 2008) makes a powerful call for emergency action, publicly endorsed by Jim Hansen and other prominent experts.[51]

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[50] This work was pioneered by climate scientists at the Met Office Hadley Centre in Exeter, United Kingdom. The timeline can be further traced back to a previous paper by Met Office's Richard Betts and Peter Cox and two plant scientists from the University of Sheffield which studied climate model feedbacks from changes in vegetation structure (Betts et al. 1997). Unlike Cox et al. (2000), the previous paper only compared the impact on the global mean temperature increase in a limited sense. It found that changes in vegetation structure largely offset physiological vegetation-climate feedbacks in the long term (with some significant regional-scale effects).

[51] The book was followed up by the launch of *Safe Climate Australia* in Melbourne, Australia, in July 2009, by former Vice President Al Gore (http://www.safeclimateaustralia.org/). The new organization is seen as a model for similar groups in other countries to develop whole-of-society plans to restructure economies from fossil fuels to reach "net-zero carbon" at emergency speed. Al Gore had already launched similar ventures in the US, including *Repower America* in 2008, which aims at converting all electricity supplies to clean power (http://www.repoweramerica.org/). The venture is one of several under the auspices of *The Alliance for Climate Protection*, founded by Al Gore in 2006 to alert the global community to the urgent need for comprehensive solutions to the climate crisis. The non-profit, non-partisan Alliance was reported in late 2009 to have more than two million members worldwide (http://www.climateprotect.org/ ).

The prevalent macroeconomic policy model has also been dealt a blow by the global economic crisis. George Akerlof, joint winner of the 2001 Nobel Prize in economics, and Yale economics professor Robert Shiller, find that the conventional theory is not providing anything like an adequate explanation. Their book is *Animal Spirits: How human psychology drives the economy, and why it matters for global capitalism* (Akerlof and Shiller 2009). The 'animal spirits' were identified by John Maynard Keynes himself in Chapter 12 of his *General Theory of Employment, Interest and Money* (1936); but that part of the Keynesian message was diluted quite rapidly.

As the Florida Keys project entered its second year, it became clearly inappropriate to ignore the economic events of 2008 even if the task of building climate-change scenarios is to take a long-term view. All scenario analysis must address rule-changing issues, and the recession that spread from the United States to the rest of the world is changing macroeconomic thinking and policy. So climate change and the economic crisis both force a reconsideration of economic and financial policy.

This appendix begins with a description of the acknowledged influence of Keynes's "animal spirits" on the business cycle and then proceed to an examination of the new economics of climate change. Because it relates to the current financial and economic downturn we then touch on recent attempts by various scientific disciplines to come to the "aid" of economic theory (mainly on how to predict "bubbles" or fluctuations in confidence affecting stock, residential and other markets).

More important and relevant in the interdisciplinary context, however, is the development of what started as a science-based set of ideas around what Nobel Prize-winning physicist Murray Gell-Mann has called "an emerging synthesis at the cutting edge of inquiry into the character of the world around us – the study of the simple and the complex" (Gell-Mann 1994, p ix). *Complexity theory* in the past two decades has spread across the physical, biological and behavioral sciences, and may have a decisive influence on economic thinking in the future.

Since economics and psychology are both behavioral sciences, recent contributions by psychologists on how to persuade people to accept the urgency of the climate change challenge are also potentially important for the future development of economic theory and its influence on government policy. The American Psychological Association in 2009 published a major report on the subject. As well as warranting a special heading in relation to climate change in this appendix, psychology provides essential understanding of the "animal spirits" in the section below.

The last section but one contains an attempt to pull the three main strands of the analysis together in preparation for the inclusion of economic and financial policy philosophies into the four main scenarios. Climate change policy is then discussed in the final section in the context of the past year's events: the continued impact of the global crisis which began in the United States in 2008, the failure in 2009 to pass emissions trading (ETS) schemes in the USA and other countries including Australia (associated with the general rise of climate change deniers), and the outcome of the UNFCCC Conference of the Parties in Copenhagen in December 2009 (COP-15), which was influenced by these recent developments.

# *ANIMAL SPIRITS* AND THE GLOBAL FINANCIAL CRISIS

## THE HEART OF AKERLOF AND SHILLER'S MESSAGE

"The proper role of government … is to set the stage. The stage should give full rein to the creativity of capitalism. But it should also countervail the excesses that occur because of our animal spirits." (pp ix-x)

"The belief that government should not interfere with people in pursuit of their own self-interest has influenced national policies across the globe. … Now, three decades after the elections of Margaret Thatcher and Ronald Reagan, we see the troubles it can spawn. No limits were set to the excesses of Wall Street. It got wildly drunk. And now the world must face the consequences." (p xi)

"With the general acceptance after the 1980s of the belief that capitalism was free-for-all, the playing field may have changed, but the rules of the game had not adapted. This has been nowhere more apparent than in the financial markets. … Public antipathy toward regulation supplied the underlying reason for this failure. The United States was deep into a new view of capitalism. We believed in the no-holds-barred interpretation of the game. We had forgotten the hard-earned lesson of the 1930s: that capitalism can give us the best of all possible worlds, but it does so only on a playing field where the government sets the rules and acts as a referee." (pp 172-173)

## ORIGIN AND NEGLECT OF THE ANIMAL SPIRITS

### *Keynes' General Theory of Employment, Interest and Money*

Chapter 12 of the *General Theory* (Keynes 1936), on long-term expectations, is at a "different level of abstraction" from the rest of the book (p 149). An addendum to this appendix summarizes Chapter 12, with Section VII on animal spirits reproduced in full. Basically: "The state of long-term expectation, on which our decisions are based, does not solely depend … on the most probable forecast we can make. It also depends on the *confidence* with which we make this forecast – on how highly we rate the likelihood of our best forecast turning out quite wrong." (p 148)

The uncertainty of long-term forecasting causes investors to rely on a *convention* that the current state of affairs will continue indefinitely, except when there is reason to expect a change. The existing market valuation is considered uniquely *correct* in relation to our existing knowledge of the facts which will influence the yield of the investment. [52]

[52] Akerlof and Shiller are by no means alone in evoking Keynes – the chorus is growing. *The Economist* on October 1, 2009, reviewed three new British-published books under the heading of *The Keynes comeback* (by Peter Clarke: *Keynes: The Twentieth Century's Most Influential Economist*), Robert Skidelsky (*Keynes: The Return of the Master*), and Paul Davidson (*The Keynes Solution: The Path to Global Economic Prosperity*)). The reviewer agrees that "Keynes's disciples are right that their prophet's visions go far beyond the stimulus packages with which his name is now associated" – though it is less clear "what Keynes would have done" in the current economic situation. All three books, however, agree that by "ignoring irreducible uncertainty, modern economics had gone fundamentally off course. Those intellectual errors, in turn, prompted huge policy errors, such as relying on deregulated financial markets." This is also Akerlof and Shiller's fundamental thesis.

The weak points of the convention – relating to what Keynes called the *state of confidence* – are:

1. Real knowledge has declined with the rising influence of stock exchanges which have separated ownership from management – managers know their business; owners of shares have generally no direct knowledge.
2. Ephemeral day-to-day fluctuations in profits "tend to have an altogether excessive, and even an absurd, influence on the market."
3. A conventional valuation based on the mass psychology of "ignorant individuals" can swing violently in the opposite direction as mass opinion fluctuates "due to factors which do not make much difference to the prospective yield."
4. Stock market experts are less interested in making superior long-term forecasts for the benefit of shareholders than in "forecasting changes in the conventional basis of valuation a short time ahead of the general public." (*General Theory,* p 154)

A fifth weak point is the extent of confidence not of the speculative investors themselves but the confidence of the lending institutions towards those who seek to borrow from them (known as the *state of credit*). "A collapse in the price of equities … may have been due to the weakening either of speculative confidence or of the state of credit. But whereas the weakening of either is enough to cause a collapse, recovery requires the revival of *both*. For whilst the weakening of credit is sufficient to bring about a collapse, its strengthening, though a necessary condition of recovery, is not a sufficient condition." (p 158)

Keynes distinguished between *speculation* (the activity of forecasting the psychology of the market) and *enterprise* (the activity of forecasting the yield of assets over their whole life). He found that the influence of speculation on Wall Street is enormous, because Americans tend to buy stock for capital appreciation, whereas the British are (were?) more interested in long-term profit. (p 159)

Human nature, according to the focal Chapter VII, causes activities to depend on spontaneous optimism rather than mathematical expectation. People have a spontaneous urge to act which can only be taken as a result of *animal spirits*. "Enterprise will fade and die if the animal spirits are dimmed and the spontaneous optimism falters … . This means, unfortunately, not only that slumps and depressions are exaggerated in degree, but that economic prosperity is excessively dependent on a political and social atmosphere which is congenial to the average business man." (p 162)

While Keynes is careful not to exaggerate the influence of irrational optimism, he does advocate in his conclusion to Chapter 12 that the State should take "greater responsibility for directly organizing investment." Monetary policy is insufficient: "… the fluctuations in the market estimation of the marginal efficiency of different types of capital, calculated on the principles I have described above, will be too great to be offset by any practicable changes in the rate of interest." (p 164)

***How the animal spirits came to be neglected***

Akerlof and Shiller note in their preface (p x): "Following the publication of *The General Theory*, Keynes' followers rooted out almost all of the animal spirits – the noneconomic motives and irrational behaviors – that lay at the heart of his explanation for the Great Depression." One reason was that the aggregate model that Keynes built suited the nascent mathematical subject of econometrics – including his multiplier effect which stipulates that the ultimate impact of an initial increase in income (derived, for example, from increased government expenditure) is a function of the ratio between the marginal propensity to consume (MPC) and the increase in income. Thus, if the MPC is 0.8 because people spend 80% of their increased income and save 20%, the multiplier is 5; if the MPC is 0.5, the multiplier is 2.

This development happened quite quickly led by a group of future Nobel economics prize winners. John R. Hicks published a quantitative interpretation of Keynes' *General Theory* that highlighted a rigid multiplier and the interaction of its effects with interest rates (Hicks 1937).[53] Formal econometric models of total economies followed in the ensuing ten years (Jan Tinbergen from as early as 1936 when he published the world's first econometric model, of the Dutch economy; Lawrence Klein from 1946), as well as the development of national income and expenditure statistics in the 1940s which were tailor-made for econometric databases. Finally, in 1947, another future winner of the Nobel Prize in economics, Paul Samuelson, wrote *Foundations of Economic Analysis*, which more than any other work defined economic theory in mathematical terms and pointed the way to the neoclassical school of economics.

Animal spirits were neglected, and in any case didn't fit well into to the econometric models that became technically possible while computing capacity remained modest.

*Neoclassical macroeconomics* emerged as a school during the 1970s, which Akerlof and Shiller said did away with whatever animal spirits remained in post-Keynesian thought (p x). We cannot hope to give justice to a major new economic school in a few sentences, and there are survey papers (such as Hoover 2008) which provide comprehensive descriptions. The following will have to suffice.

Neoclassical economics tried to explain consumption, investment, the demand for money and other elements of the aggregate Keynesian model in a manner consistent with the classical microeconomic assumption that individual and firms behave optimally. 'Optimally' implies 'rationally'. This means, among other things, that economic decisions by individuals and firms are based on real rather than nominal or monetary factors (there is no "money illusion"), and that they generally hold on to their rational expectations. In other words, Keynesian animal spirits were dismissed as insignificant or irrelevant.

This takes us to the situation today, when the economic crisis has hit home, and to Akerlof and Shiller's analysis.

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[53] In the 1937 paper, Hicks invented the so-called IS/LM model to formalize Keynes' General Theory. IS originally stood for investment-savings equilibrium but came to represent the locus of all equilibria where total spending (consumption plus planned investment plus government purchases plus net exports) equals total output or GDP. LM (LL in the Hicks paper) represented the role of finance and money, showing the equilibrium between liquidity preference (the preference for holding cash balances rather than securities) and the money supply. (http://en.wikipedia.org/wiki/IS/LM_model).

### *Five expressions of animal spirits*

Akerlof and Shiller identify *confidence*, *fairness*, *corruption and antisocial behavior*, *money illusion*, and *stories* as expressions or aspects of animal spirits that economists should acknowledge (pp 5-6):

1. "The cornerstone of our theory is *confidence* and the feedback mechanisms between it and the economy that amplify disturbances." [They describe the "confidence multiplier" on pp 14-15.]
2. The setting of wages and prices depends largely on concerns about *fairness.*
3. We acknowledge the temptation toward *corrupt and antisocial behavior* and their role in the economy.
4. *Money illusion* is another cornerstone. The public is confused by inflation or deflation and does not reason through the effects. [Compare the neoclassical macroeconomics described above.]
5. Finally, our sense of reality, of who we are and what we are doing, is intertwined with the story of our lives and of the lives of others. The aggregate of such *stories* is a national or international story, which itself plays an important role in the economy."

Each of these can be used to contrast standard economic theory and real behavior, as summarized in Figure 1 which contrasts conventional macroeconomics with models that take animal spirits into account:

Figure 1: Two views of macroeconomics

| Conventional economics | Plus animal spirits |
|---|---|
| **CONFIDENCE** Decisions are based on weighting probability of each outcome | Not based on rational decisions. Confidence is the first and most crucial of the animal spirits |
| **FAIRNESS** Large economic literature but fairness traditionally seen as secondary factor | Basic economic activities including wage and price fixing need fairness as part of explanation |
| **CORRUPTION/BAD FAITH** Conventional economics based on maximizing profits is basically amoral | The business cycle is influenced by fluctuations in poorly controlled predatory activity |
| **MONEY ILLUSION** Price & wage decisions are driven by real, not nominal values | People are unable to see through the veil of inflation and for example, avoid using indexation |
| **STORIES** Economists prefer quantitative facts and figures for optimization | Epidemics of confidence or lack of confidence based on 'stories' have real effects on markets |

Source: Akerlof and Shiller (2009), Part 2: *Animal Spirits*

***Confidence***: "When people make significant investment decisions, they must depend on confidence. Standard economic theory suggests otherwise. It describes a formal process for making rational decisions: People consider all the options available to them. They consider the outcomes of all these options and how advantageous each outcome would be. They consider the probabilities of each of these options.

And then they make a decision.

But can we really do that? Do we really have a way to define what those probabilities and outcomes are? Or, on the contrary, are not business decisions ... made much more on the basis of whether or not we have confidence? … [At] the level of the macroeconomy, in the aggregate, confidence comes and goes. Sometimes it is justified. Sometimes it is not. It is not just a rational prediction. It is the first and most crucial of our animal spirits." (pp 13-14)

***Fairness***: "Considerations of fairness are a major motivator in many economic decisions and are related to our sense of confidence and our ability to work effectively together. Current economics has an ambiguous view of fairness. While on the one hand there is a considerable literature on what is fair and unfair, there is also a tradition that such considerations should take second place in the explanation of economic events.

We insist that if such motivations are to be given lower status in economic argument, then justification must be given. On the contrary, we think phenomena as basic as the existence of involuntary unemployment and the relation between inflation and aggregate output can be easily explained when fairness is taken into account." (p 25)

***Corruption and bad faith***: "If we wish to understand the functioning of the economy, and its animal spirits, we must also understand the economy's sinister side – the tendencies toward antisocial behavior and the crashes that disrupt it at long intervals or in hidden places." (p 26)

"The usual symbols of what makes capitalism work are the go-get-'em CEOs who pride themselves on being aggressive and tough risk-takers. … But it is precisely because there are these CEOs, so unapologetic about making a buck for themselves and their companies, that there is a need for a counterbalance, to ensure that all of this energy does not spill over into dishonesty. This counterbalance comes in the form of accountants, so well known for their stable personalities and their probity. … They are the cool-minded sheriffs of its Wild West." (p 29)

Unfortunately this is not always so, and what follows suggests that the authors were rather tongue-in-cheek in the above passage, or at least that there are some gross exceptions to their rule. The Savings & Loans (S&L) Associations in the United States act as banks that lend money primarily for mortgages. "Clever accounting practices" were instituted to allow the S&Ls to stay in business in the 1980s when they should have been technically bankrupted – the fact that they were not was exploited by the "junk bond impresario Michael Milken" who became the most inventive user of "S&L sweetheart money" (described in detail on pp 30-32). "The S&L crisis was ultimately responsible for a considerable amount of the economic turmoil that disturbed the economy during the recession of 1990-91 and for the slow recovery that followed it, lasting until 1993." (p 32)

During the 2001 recession, Enron's accountants, one of the then "big five" accounting firms, Arthur Andersen, failed to blow the whistle on the fraudulent practices that proliferated. "They were afraid that if they did so they would lose the rich consulting contracts that Enron was also giving them. It was yet another sweetheart deal. An economist would describe this situation as an equilibrium. Everyone was following his own self-interest. But the public was buying snake oil. The recession of 2001 offered ample evidence that this equilibrium was by no means mutually beneficial for all concerned." (p 35)

The three recent recessions in the United States – 1990-91, 2001, and the current one set off by the subprime crisis of 2007 and precipitated by the Lehman Brothers collapse in September 2008 – provide examples of changes in the nature of predatory activity. "These examples illustrate that the business cycle is connected to fluctuations in personal commitment to principles of good behavior and to fluctuations in predatory activity, which in turn is related to changes in opportunities for such activity.

Why do new kinds of corrupt or bad-faith behavior arise from time to time? Part of the answer is that there are variations through time in the perceived penalties for such behavior. … In a time of widespread corrupt activity, many people may get the impression that it is easy to get away with it." (p 38)

***Money illusion*** is "another missing ingredient in modern macroeconomics. Money illusion occurs when decisions are influenced by nominal dollar amounts. Economists believe that if people were "rational" their decisions would be influenced only by what they could buy or sell in the marketplace with those nominal dollars. In the absence of money illusion, pricing and wage decisions are influenced only by relative costs or relative prices, not by the nominal values of those costs or prices." (p 41)

"We have seen that one of the most important assumptions of modern macroeconomics is that people see through the veil of inflation. That seems to be an extreme assumption. It also seems totally implausible given the nature of wage contracts, of price setting, of bond contracts, and of accounting. These contracts could easily throw aside the veil of inflation through indexation. Yet the parties to the contracts in most cases choose not to. And these are but a few indications of money illusion. We shall see that taking money illusion into account gives us a different macroeconomics – one that arrives at considerably different policy conclusions. Once again animal spirits play a role in how the economy works." (p 50)

***Stories***: "The human mind is built to think in terms of narratives, of sequences of events with an internal logic and dynamic that appear as a unified whole. In turn, much of human motivation comes from living through a story of our lives, a story that we tell to ourselves and that creates a framework for motivation. … The same is true for confidence in a nation, a company, or an institution. Great leaders are first and foremost creators of stories." (p 51)

"It is generally considered unprofessional for economists to base their analysis on stories.[54] On the contrary, we are supposed to stick to the quantitative facts and theory – a theory that is based on optimization, especially optimization of economic variables. Just the facts, ma'am. There is good reason to be careful about the use of stories. The news media are,

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[54] *What about our scenarios if stories are considered an unacceptable economic tool?* Stories are at the root of the scenario analysis which is the end product in the Florida Keys project. But the IPCC scenarios represent carefully constructed possible alternative future worlds chosen to set the boundaries of what is regarded as plausible – they describe the credible range of what might happen in an unpredictable future. Scenario analysis represents a recognized approach to test what may plausibly happen – complemented by quantitative future estimates of selected socioeconomic, demographic, and biophysical variables. Their connection with real policy is solely through the recommendations that follow at the end of the study. The premises are there for all to see and assess, and do not lead to an "epidemic of stories" serving particular vested interests.

after all, in the business of creating stories that people would like to hear. Thus there is a tendency toward overexplanation of economic events. Just look at the theories offered by pundit after pundit on a slow news day when stocks have moved by a fair amount. Thus economists are rightly wary of stories and of the reality they seek to define." (p 54)

The stories, however, may themselves move markets, have real effects. We can have epidemics of stories as much as epidemics of disease. "Just as epidemics spread through contagion, so does confidence, or lack of confidence. Indeed confidence, or the lack thereof, may be as contagious as any disease. Epidemics of confidence or epidemics of pessimism may arise mysteriously simply because there was a change in the contagion rate of certain modes of thinking." (p 56)

***Eight key questions and the influence of animal spirits***

Part 2 of *Animal Spirits* (pp 57-166) poses eight fundamental questions, all relevant in the context of animal spirits but beyond the scope of this appendix:

1. Why do economies fall into depression?
2. Why do central bankers have power over the economy?
3. Why are there people who cannot find a job?
4. Why is there a trade-off between inflation and unemployment in the long run?
5. Why is saving for the future so arbitrary?
6. Why are financial prices and corporate investments so volatile?
7. Why do real estate markets go through cycles?
8. Why is there special poverty among minorities?

"The real problem … is the conventional wisdom that underlies so much of current economic theory. So many members of the macroeconomics and finance profession have gone so far in the direction of "rational expectations" and "efficient markets" that they fail to consider the most important dynamics underlying economic crises. Failing to incorporate animal spirits into the model can blind us to the real sources of trouble.

The crisis was not foreseen [by bureaucrats and politicians] … because there have been no principles in conventional economic theories regarding animal spirits. Conventional economic theories exclude the changing thought patterns and modes of doing business that bring on a crisis. They even exclude the loss of trust and confidence. They exclude the sense of fairness that inhibits the wage and price flexibility that could possibly stabilize an economy. They exclude the role of corruption and the sale of bad products in booms, and the role of their revelation when the bubbles burst. They also exclude the role of stories that interpret the economy. All of these exclusions from conventional explanations of how the economy behaves were responsible for the suspension of disbelief that led up to the current crisis. They are also responsible for our current failure in knowing how to deal with the crisis now that it has come." (p 167)

"It is necessary to incorporate animal spirits into macroeconomic theory in order to know how the economy really works. In this respect the macroeconomics of the past thirty years has gone in the wrong direction. In their attempts to clean up macroeconomics and make it more *scientific*, the standard macroeconomists have imposed research structure and discipline by focusing on how the economy would behave if people had only economic motives and if they were also fully rational." (p 168)

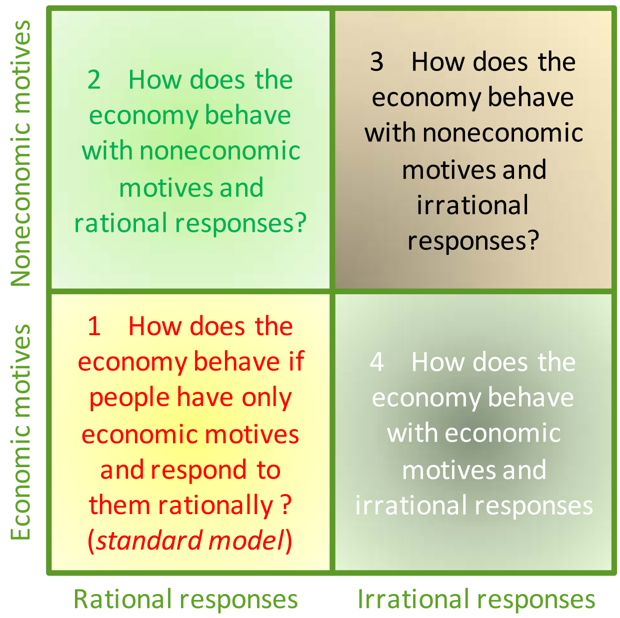
This is the model depicted by the lower left quadrant of Figure 2, drawn from the text of page 168 of *Animal Spirits*. Akerlof and Shiller advocate a description of all four quadrants combining economic versus noneconomic motives and rational versus irrational responses. They conclude:

"We believe that the answers to the most important questions regarding how the macroeconomy behaves and what we ought to do when it misbehaves lies largely (though not exclusively) within those three blank boxes." (p 168)

Akerlof and Shiller use events since 2000 as a test, noting that it is in a nutshell what happened toward the current financial crisis (pp 169-170):

- In the stock market crash in 2000 "the economy recoiled from the irrational exuberance of the dot-com years."
- Overconfidence took hold in the housing boom from 2001 to 2005: "People began to buy housing as if this were their last chance ever to buy a house .. and speculators began to make investments in housing, as if other people were going to think that they should buy now, at almost any price, because they would not be able to afford to buy a house later."

Figure 2: Extending the macroeconomic model




Source: Akerlof and Shiller (2009), p 168 text: 'How macroeconomic theory must respond'

- "The financial markets – which are supposed to be so cautious – aided and abetted the process. Of course, the real estate dealers and the mortgage brokers had no reason to dampen the fever. They were collecting [enormous] transaction fees. .. Most surprisingly, those on the other side of the ledger took in those mortgages and gave the home buyers the massive funds they needed for their unwise speculations."
- "The rating houses based their estimates of the probability of default of mortgages .. on recent trends in home prices – and those had always gone up. So there appeared to be little reason to fear default in this case. Even if someone in a rating agency had thought

that the opposite was true – that the ratings should also incorporate the possibility that home prices might decline – anyone who actually blew the whistle would make herself immensely unpopular by casting aspersions on the whole parade of fee collectors who were getting so rich so quickly."

### STIGLITZ AND OTHER ECONOMISTS ON A PARALLEL COURSE

One of Akerlof's two fellow Nobel Prize economics winners in 2001, Joseph Stiglitz, invoked Keynes' animal spirits in his review of the East Asia crisis in 1997-98 in *Globalization and Its Discontents* (2002). "Capital market liberalization made the developing countries subject to both the rational and the irrational whims of the investor community, to their irrational exuberance and pessimism. Keynes was well aware of the often seemingly irrational changes in sentiments. … [He] referred to these huge and often inexplicable swings in mood as "animal spirits." Nowhere were these spirits more evident than in East Asia." (p 100)

The general thesis in Stiglitz's book, based on his experience as chairman of President Clinton's Council of Economic Advisers and chief economist for the World Bank in the 1990s, is a failure of globalization in much of the developing world. "Globalization today is not working for many of the world's poor. It is not working for much of the environment. It is not working for the stability of the global economy." (p 214)

In response to the global recession in late 2008, Joseph Stiglitz was appointed chairman of a United Nations committee to advise on reform of the international monetary and financial system. He notes in his introductory remarks (Stiglitz 2009): "Seventy five years ago Keynes explained why markets are not self-correcting, at least in the relevant time frame. Even when markets were Pareto efficient,[55] of course, there was no assurance that what resulted conformed to any principles of social justice—either in terms of outcomes or opportunities. More recently, theories of behavioral economics have uncovered patterns of human behavior in which individuals and groups exhibit systematic irrationalities. Yet, while there was mounting theoretical and empirical evidence concerning the appropriate domains for government intervention, some pushed an agenda downplaying the role of government, including deregulation. The success of this agenda suggests that some of the problems the world faces today can be viewed as much a problem of governance and politics as a failure of economics."

In his review of the state of financial services for *The Economist*, one of Edward Carr's papers (2009) is titled *Wild-animal spirits*. "Whenever issuers compete for market share or buyers pile in because they are afraid of missing the boat, a boom may be in the making. Investors herd together in this way because, as John Maynard Keynes argued, they do not have a sure grasp of the future. Faced with uncertainty, they resort to whatever conventions they can find to cling to, from popular wisdom to new theories. In a boom, overconfident investors take on bets that they later find themselves unable to discharge." Animal spirits displayed once more.

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[55] Informally, Pareto efficient situations are those in which any change to make any person better off would make someone else worse off. (Wikipedia)

UCLA economics professor Roger Farmer has actually tried building animal spirits into a formal economic model. He concludes that the question whether business cycles are driven by animal spirits "is likely to remain a lively and important focus of research for some time to come." (Farmer 2007, p 10).

He notes that Keynes has once again become fashionable as the world economy spirals into recession. A main aspect of animal spirits is the assumption that "confidence" is an independent fundamental determinant of economic activity (Farmer 2009, p 10). He goes as far as using "confidence" interchangeably with "animal spirits" and believes that confidence determines what Keynes called "the state of long-term expectations." (p 17)

### A STRATEGIC BUSINESS VIEW OF THE CRISIS

"Management lessons from the financial crisis" (Webb 2009) reflects the views of two leading business strategists, Lowell Bryan of McKinsey's New York office and UCLA strategy professor Richard Rumelt. It reflects on the broad managerial implications of the crisis. There is no mention of animal spirits but they obviously lurk. This is from the microeconomic coalface which was first ignored by macroeconomists, and then treated as if individuals and firms behaved rationally. This mistake is unlikely to be repeated for a decade or more, though the lesson may be once again forgotten as the century rolls on.[56]

Rumelt notes a dramatic failure in management governance. He calls it the "smooth sailing" fallacy, referring to the *Hindenburg* airship that did hundreds of successful and comfortable flights before it burst into flames unexpectedly over New Jersey in May 1937. The ride in the *Hindenburg* was smooth until it exploded. "If you had a modern econometrician on board, no matter how hard he studied those bumps and wiggles in the ride, he wouldn't have been able to predict the disaster. The fallacy is the idea that you can predict disaster risk by looking at the bumps and wiggles in current results. … The history of bumps and wiggles – and of GDP and prices – didn't predict economic disaster. … What happened to the *Hindenburg* that night was not a surprisingly large bump. It was a design flaw."

"This smooth-sailing fallacy arises when we mistake a measure for reality. Competent management always looks deeper than the numbers, deeper than the current measures. Incompetent management just focuses on the metrics, on the body count, on quarterly earnings – or on GDP growth or the consumer price index. And that's how we get into these troubles."

Looking beyond the numbers at the deeper issues is invoking animal spirits, though these are left unmentioned. Animal spirits controlled by competent managers are important for business success, and ultimately for the success of our capitalistic system. The animal spirits

[56] The lesson may be forgotten in less than a decade, unless there is an institutional change in the way the financial information is analyzed and promulgated. Between 1985 and 2009, financial analysts were persistently overoptimistic; their forecasts were almost 100% too high on average. A 5-year rolling average of earnings growth for the S&P 500 companies showed little relationship between forecasts ranging between 11 and 18% (the latter associated with the high-tech or "dot-com" bubble from 1995 to 2000). Compared with an average of 7% for actual earnings, the analysts' forecasts averaged 13% for the 25 years. Furthermore, the forecasts become even less accurate as economic growth declines and analysts are slow to adjust to reality. The 5-year average forecast by analysts for 2004-09 was about 12%, but the actual figure, at -2%, turned negative for the first time in the 25 years (Goedhart et al. 2010, Exhibit 2). The previous low point, associated with the "dot-com" bubble, showed the actual average for 1997-2002 decline to 1%, compared with the analysts' forecast of nearly 14%.

that led to the "smooth sailing" fallacy are more damaging. But macroeconomic thinking can no longer ignore them.

Lowell Bryan sums up his version of the fallacy: "One of the other things that really characterized the period from about 1982 until literally last year was that economic volatility – in terms of degree and depth of business cycles – and financial volatility measurably declined. Basically, people assumed they were always going to have flat seas. There weren't going to be storms. And they built up a set of business practices and strategies which may have had really deeply flawed assumptions, as Richard was saying. A lot of people do things because if it's been good for the last three years, they assume it's going to be good for another year.

I think that we are now into a period where whole generations of people – consumers, managers – who had been lulled into the view that the world was not volatile, now know in their gut that it is in a way that you couldn't describe to them before. And I think that's going to have unknown behavioral effects and unknown economic effects."

### SCIENTISTS OFFER TO RE-DEFINE ECONOMIC THEORY

The alleged failure of conventional economic theory to recognize 'animal spirits' has renewed suggestions from the natural sciences that their input might be helpful and maybe even decisive. Some scientists claim that emerging market bubbles can be detected through the mathematical patterns they generate, even suggesting that seismological techniques may help calculate the likely frequency of market fluctuations. That is not an idle claim; mathematical "power curves" have been shown to describe a wide range of both natural and economic phenomena, where a short "head" of frequently occurring small events drops off to a long "tail" of increasing rare but much larger ones (Zanini 2009).[57] The issue is how these distributions can be used to predict actual events like the global financial crisis.

Economists Robert Shiller and Karl Case comment that "purely mathematical approaches have a big drawback: the irrational response of people. In any bubble, those making big profits will find arguments as to why this time the underlying maths should be different. Before the dot-com bubble burst in 2000, the reasoning was that the Internet had created a "new economy"; in the build-up to the current crisis, people said that financial engineering had made mortgage risk a thing of the past." (Buchanan 2009, p 34)

The efforts by scientists reported above are part of an interdisciplinary research field named *econophysics* in the mid-1990s, referring to the work of several physicists working in the area of statistical mechanics. They decided to tackle the complex problems of uncertain or

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[57] Power laws are currently being applied to weather forecasting (possibly capable of being expanded to climate modeling), based on the observation that patterns in nature repeat themselves at different scales from very large to very small (a feature of the "fractals" in chaos theory). The problem has been that the power curves developed here typically need more than one exponent, but the scientists involved, led by Shaun Lovejoy, are now reported to be working with NOAA in Boulder, Colorado, on incorporating multifractal techniques into live computer models of the atmosphere, with the aim of making both weather and climate models reliable at the finest scale possible. If successful, this would eventually reduce the high uncertainty in climate modeling, though "it may take some years before the techniques are implemented." (Matthews 2009)

Power laws are related to Martin Weitzman's "fat-tailed" distributions in which the tail probability approaches zero more slowly than exponentially (Weitzman 2009).

stochastic processes and nonlinear dynamics typically posed by stock market fluctuations. Papers on econophysics have been published primarily in journals devoted to physics and statistical mechanics, rather than in leading economics journals. Mainstream economists are reported to have been generally unimpressed by this work.[58] There is, however, more to this than meets the eye, as reported in the section on genuine interdisciplinary influences, below, with reference to the role of econophysics in complexity economics.

Economics itself may have become overly mathematical and driven by the neoclassical model over the past half-century, and needs to stand back and look at its basic assumptions. There are signs that this is happening. The debate on the inadequacies of economic theory intensified during 2009, and subsequent sections show that serious re-evaluation is underway led by economists who were already engaged in a deep reassessment of their discipline. The insights from other branches of learning are important but the remedies must be defined within what is after all a well-established social science in its own right. That said, a growing number of economists agree that the “supply-side economics” advocated in the Reagan and Thatcher years, holding that reducing tax rates for businesses and wealthy individuals stimulates savings and investment for the benefit of everyone through “trickle-down” effects, and the markets being freed from regulations, has led the world down a dangerous path.

Two other theories buttressed supply-side economics: “rational expectations” and the “efficient market” hypothesis, proclaiming that traders do not make systematic errors when predicting the future, and that the prices of shares, bond and physical property accurately reflect all relevant information. Biochemist Terence Kealey (2009) rightly queries such precepts of conventional economic theory.

Kealey’s main thesis is more debatable, that science is technology-driven and technology is profit-driven and that science is therefore not in need of government funding. Science is ostensibly regarded by economists as a public good in the sense that its results are generally accessible – causing alleged *market failure* because no private company will pay for research when its benefits go to others. In the real world, however, billions of research-and-development dollars are expended by major corporations in the pursuit of financial profitability, benefiting from the time lag before competitors can catch up with what Kealey calls the relevant tacit knowledge of the innovators, as well as the constraining influence of intellectual property regulations, and the cost to competitors of copying innovations, employing scientists, and building the necessary infrastructure.

The issue is critical in the context of the greatest market failure, climate change, the economics of which is taken up in the next main section. To have governments withdraw from supporting the funding of the big transition needed to go from fossil to renewable energy, and the rest, would verge on the suicidal. The climate change predicament highlights the distinction between scientific and technological research undertaken for purely commercial motives and the research needed to underpin renewable energy and other technologies which will start to prosper only under strong and determined public policy

[58] From http://en.wikipedia.org/wiki/Econophysics, accessed September 23, 2009. The judgment may be unduly harsh, though some efforts quoted in the present section appear to be more than a little naïve.

leadership and in conditions of reduced market failure and other political and commercial obstacles. Kealey fails to make that distinction.

## NEW ECONOMICS OF UNCERTAINTY AND RISK

Economists are working to meet the challenges outlined in the previous section, with some sophisticated responses on the treatment of risk. Professor Andrew Lo leads the Laboratory for Financial Engineering at the MIT Sloan School of Management. It is described as "a partnership between academia and industry designed to support and promote quantitative research in financial engineering and computational finance." [59]

Lo and Mueller (2010) note: "The quantitative aspirations of economists and financial analysts have for many years been based on the belief that it should be possible to build models of economic systems – and financial markets in particular – that are as predictive as those in physics." The book that perhaps more than any other contributed to the demise of Keynesian "animal spirits" in economic theory, Paul Samuelson's *Foundations of Economic Analysis* (1947), was itself heavily influenced by the mathematician and polymath scientist Edwin Bidwell Wilson, whose mathematical economics seminar he attended in 1935-36. "I was vaccinated early to understand that economics and physics could share the same formal mathematical theorems, .. while still not resting on the same empirical foundations and certainties." (Samuelson 1998, p 1376)[60]

The contrast with physics motivated Lo and Mueller to propose a "taxonomy of uncertainty" – a continuum ranging from "Level 1" (complete certainty) through "risk without uncertainties", "fully reducible uncertainty" and "partially reducible uncertainty" to "Level 5" (irreducible uncertainty, which "cannot be modeled quantitatively, yet has substantial impact on the risks and rewards of quantitative strategies"). They suggest that physicists rarely venture as far as "Level 4" (partially reducible uncertainty), but that "in this respect, economics may have more in common with biology than physics."

The financial crisis, according to Lo and Mueller (2010) "has re-invigorated the longstanding debate regarding the effectiveness of quantitative methods in economics and finance. Are markets and investors driven primarily by fear and greed that cannot be modeled, or is there a method to the market's madness that can be understood through mathematical means"?[61] They attempt to reconcile the two sides of the debate tracing the intellectual origins of the conflict to what they call "physics envy." "The quantitative aspirations of economists and financial analysts have for many years been based on the belief that it

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[59] http://lfe.mit.edu/about/intro.htm.

[60] Samuelson added that he was perhaps Wilson's only disciple ((1998, p 1376). One of the three other economists attending the seminar was Joseph Schumpeter, more than 30 years Samuelson's senior, on whom the mathematical "vaccination" worked differently if at all (see Appendix 6 on Schumpeter's profound influence on the modern theory of technology). The others were Samuelson's contemporaries (around 20 years old at the time and also destined for fame) Abram Bergson and Sidney Alexander.

[61] This seems to contrast with Shiller's and Case's view in the previous section (as reported in Buchanan 2009), but the difference may be more apparent than real in view of Lo and Mueller's taxonomy of uncertainties and their subsequent comments reported in the above text.

should be possible to build models of economic systems that are as predictive as those in physics."

They conclude that just as scientific principles are compact distillations of much more complex phenomena, specific subject areas of economic theory capture an expansive range of economic phenomena, despite their seemingly simplistic assumptions. "However, any virtue can become a vice when taken to an extreme, particularly when that extreme ignores the limitations imposed by uncertainty. .. In this respect, the state of economics may be closer to disciplines such as evolutionary biology, ecology, and meteorology."

"So what does this imply for the future of finance? Our hope is that the future will be even brighter because of the vulnerabilities that the recent crisis has revealed. By acknowledging that financial challenges cannot always be resolved with more sophisticated mathematics, and incorporating fear and greed into models and risk-management protocols explicitly rather than assuming them away, we believe that the financial models of the future will be considerably more successful, even if less mathematically elegant and tractable. Just as biologists and meteorologists have broken new ground thanks to computational advances that have spurred new theories, we anticipate the next financial renaissance to lie at the intersection of theory, practice, and computation."

An earlier paper on "the origin of behavior" (Brennan and Lo 2009) proposes "a single evolutionary explanation for the origin of several behaviors that have been observed in organisms ranging from ants to human subjects, including risk-sensitive foraging, risk aversion, loss aversion, probability matching, randomization, and diversification."

The evolutionary origin of behavior has important implications for economics. "Specifically, much of neoclassical economic theory is devoted to deriving the aggregate implications of individually optimal behavior, i.e., maximization of expected utility or profits subject to budget or production constraints. By documenting departures from individual rationality, behavioral critics argue that rational expectations models are invalid and irrelevant. Both perspectives are valid but incomplete."

"Animal behavior is, in fact, the outcome of multiple decision making components .. that each species has developed through the course of evolution. What economists consider to be individually rational behavior is likely to emanate from the prefrontal cortex, a relatively new component of the brain on the evolutionary timescale, and one that exists only in *Homo sapiens* and certain great apes." However, the human brain also contains considerably older structures linked to primitive and aggressive responses. "In the face of life-threatening circumstances, even the most disciplined individual may not be able to engage in individually rational behavior thanks to adaptive "hard-wired" neural mechanisms that conferred survival benefits to the species (and not necessarily to any given individual)."

"A better understanding of this pattern may allow consumers, investors, and policymakers to manage their risks more effectively. .. In short, the behaviors derived in our evolutionary framework may well be the "animal spirits" that Keynes .. singled out seven decades ago, and which is apparently still a force to be reckoned with today."

The behavioral research by Andrew Lo and his colleagues is interesting not only by pointing a way forward for important parts of economic theory, but also for showing the links with natural science, contrasting a past influence from physics on the leading economic research of the 1940s with the observation that "the state of economics may be closer to disciplines such as evolutionary biology, ecology, and meteorology. .. And for the truly global challenges such as climate change, the degree of subjectivity and uncertainty gives rise to spirited debate, disagreement, and what appears to be chaos to uninformed outsiders. Should we respond by discarding all forecasting models for predicting rainfall, or should we simply ignore the existence of hurricanes because they fall outside our models?

Perhaps a more productive response is to delineate the domain of validity of each model, to incorporate this information into every aspect of our activities, to attempt to limit our exposure to the catastrophic events that we know will happen but which we cannot predict, and to continue developing better models through data collection, analysis, testing, and reflection, i.e., becoming smarter." (Lo and Mueller 2010)

Commenting in *Nature* on this work, Phillip Ball (2010) notes that the classification of uncertainty into five levels is not unlike Donald Rumsfeld's distinction (quoted in Appendix 3) between things we know we know, things we know we don't know, and things we don't know we don't know ("unk-unks"). "It is one thing to recognize the gaps and uncertainties in our knowledge of a situation, and another to acknowledge that unforeseen circumstances might entirely change the picture. The economy is .. prone to .. unknown unknowns – but economic decision making is commonly misled by confusing them with known unknowns. Financial speculation is risky by definition. Yet the danger is not that the risks exist but that the highly developed calculus of risk in economic theory — for which Nobel prizes have been awarded — gives the impression that the risks are under control." (Ball 2010)

Recognizing the five levels of uncertainty, "risk assessment in economics can be united with the way uncertainties are handled in the natural sciences. It may then become clearer where conventional economic theory is a reliable guide to planning and forecasting, and where its predictive value fails." "Economists should recognize the existence of uncertainty that their models can't capture. Economists have known since the 1960s that fluctuations in commodity prices are different. They don't fit a Gaussian distribution but are 'fat-tailed', meaning that they have a greater proportion of big deviations, compared with a bell curve. Even so, many standard economic theories have failed to accommodate this deviation from the Gaussian form .. ." (Ball 2010)

## ECONOMICS OF CLIMATE CHANGE

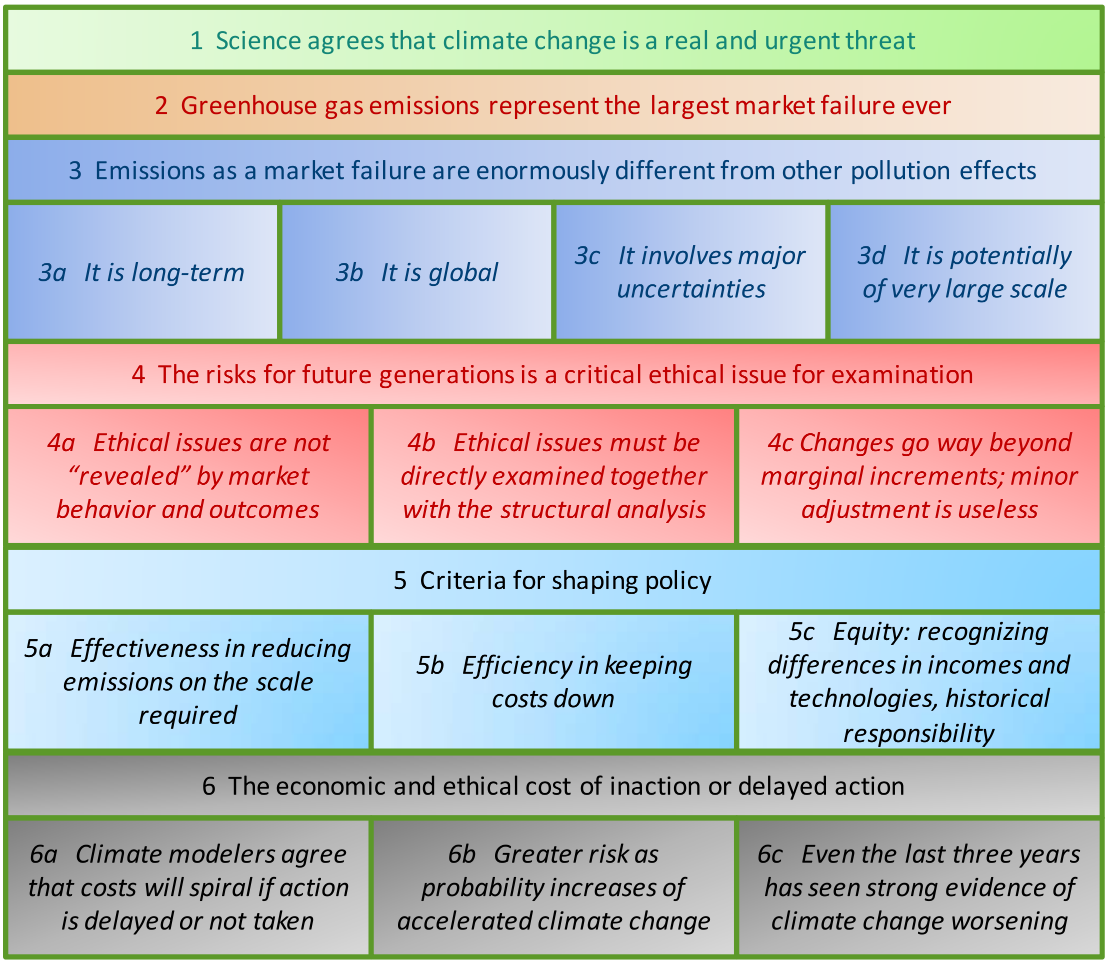
The foremost proponent in shaping climate change economics is Lord Stern, author of the *Stern Review on Climate Change* for the British Treasury (Stern 2006). Nicholas Stern was chief economist and senior vice president of the World Bank before becoming head of the Government Economic Service in the United Kingdom and Second Permanent Secretary at the UK Treasury. In 2007, after his review, he was appointed to the I. G. Patel Chair of Economics and Government at the London School of Economics. He followed the *Review* with a very readable "blueprint for a safer planet" (Stern 2009).

Before getting involved in climate change economics in 2005, Stern had built up a career-long interest in what he calls the second great challenge of the 21st century: fighting poverty, particularly in Africa. This background is important for the understanding of his work on climate change, because he sees a close connection between the two: "The two greatest problems of our times – overcoming poverty in the developing world and combating climate change – are inextricably linked." (Stern 2009, p 8)

Other economists have taken an interest in and contributed to the development of the economics of climate change. The Asian Development Bank published a major study in April 2009 listed in the references at the end of this appendix. Stern wrote the foreword. Professor Ross Garnaut published a major review for the Australian Government in September 2008 which also questions the conventional macroeconomic model.[62]

No one to date, however, has developed the theory more comprehensively than Stern. Between the *Review* and the 2009 book he repeatedly commented that he was unduly

Figure 3: Economics of climate change




Source: Stern (2006, 2009 – in particular 2009 Chapters 1 and 5)

[62] Garnaut lists four benefits from mitigation to climate change (Appendix 3). Two are actually or potentially measurable in GDP terms, and one is the insurance value from mitigation – how much are you prepared to pay to avoid a small risk of highly damaging outcome? The fourth is non-market impacts, always difficult to quantify. Garnaut postulates a utility function rising with conventional goods and services but also with environmental amenity, like the value placed on the integrity of coral reefs and other landscapes, genetic diversity and so on.

The impact of market benefits is relevant for the way the future is valued relative to the present. In terms of the pure value of time preference, the discount rate used to value future versus present should be near zero, but this is tempered to the extent future generations are likely to be richer than ours. Garnaut agrees fully with Stern that a business-as-usual scenario will lead to a very bad situation.

optimistic when he wrote the review. This includes his Richard T. Ely lecture to the American Economic Association (Stern 2008).

## THE STERN CLIMATE CHANGE MODEL

Figure 3 encapsulates Stern's message. It lists six basic propositions, shown by the headlines below as well as by the numbered items in Figure 3.

***Scientists agree that climate change is real***

A large majority of the world's scientists believe so, and that the main cause is caused by anthropogenic (human) activities. Doran and Zimmerman (2009) found that 97.4% of climatologists who are active publishers on climate change thought the main cause was anthropogenic, which is not really surprising. However, 88% of climatologists generally also thought so. This survey showed that the more scientists know about climate research, the higher is their response that anthropogenic factors are at play. But 77% of non-climatologist earth scientists also responded positively, and 58% of the general public according to a Gallup poll conducted at the time, though this leaves a significant 42% minority of deniers.[63]

Doran and Zimmerman concluded: "It seems that the debate on the authenticity of global warming and the role played by human activity is largely nonexistent among those who understand the nuances and scientific basis of long-term climate processes. The challenge, rather, appears to be how to effectively communicate this fact to policy makers and to a public that continues to mistakenly perceive debate among scientists." [64]

***The greatest market failure ever***

Economists refer to market failure when the main coordinating mechanism in a market – prices – sends the wrong signals. Prices of petrol or aluminum produced with dirty energy do not reflect the true cost to society of producing and using these goods. Without policy intervention too much of these goods will be produced and consumed. "By producing and consuming less of these products and more of others, we create economic gains that can make everyone better off. Markets with uncorrected failures lead to inefficiency and waste." (Stern 2009, p 11; page references in the following text are also from that source except when indicated.)

Market failures take many forms including lack of information, abuse of market power, and "externalities" where someone's action directly affects the prospects of others. Greenhouse gas emissions are clearly an externality and market failure because the actions of those producing them are paid for by everyone else.

***Emissions differ fundamentally from congestion or local pollution***

A company that dumps toxic waste into a river causes only local pollution, which can generally be dealt with locally. Greenhouse gas emissions are in a vastly different class because, as Figure 3 shows: it has *long-term* effects, the effects are *global*, the impact is

[63] Since grown into a majority according to opinion polls taken during 2009.

[64] Surveys in 2009 showed climate skeptics to be on the increase in the US.

highly *uncertain* but is potentially *huge*. Hence, these emissions constitute the greatest market failure the world has ever seen.

### *The risk for future generations is a crucial ethical issue*

This is the centerpiece of Stern's economics of climate change. He insists that "the heart of economic analysis must be: the ethics of values both within and between generations; international collaboration; an appreciation of risk; and changes way beyond minor adjustments, or "marginal increments" in the jargon so beloved by economists." (pp 11-12)

Stern dismisses suggestions that ethics are outside the subject of economics, or that ethics are "revealed" by market behavior or outcomes. "Economists provide analyses that inform political processes and policy and moral judgements, and that can help to shape questions. Economic analysis can show the implications of different sets of values for decisions and show inconsistencies. Moreover, while markets can provide some limited information relevant to values, there is no way they can settle debates over which values should be used to guide decisions of this magnitude, collective responsibility and timescale." (p 12)

Ethics are at the center of the debate economists have had about the extent to which the future should be discounted compared with the present, in other words what value should be placed on their benefits compared to the present generation's. In terms of the Kashmiri proverb that we have borrowed the Earth from our descendants, the discount factor should be very low, that is, there should be little difference in the valuation of benefits of the present generation and the valuation of benefits of our grandchildren's generation. This consideration is complicated by the inequalities between rich and poor countries, and also by the possibility that our descendants will be richer than we are, and therefore may have less need for additional benefits.[65] But the general conclusion is still that ethics dictate a low discount rate to value the benefits of our own generation and the future.

We have already touched upon the likelihood that the future effects of climate change takes us out of the economist's comfort zone of dealing with marginal change in costs and benefits. The economics, as Stern puts it, are much more difficult and profound. (p 13)

### *Criteria for shaping policy*

The economic policy criteria naturally include effectiveness in reducing emissions on the required scale. As we have seen, alternative policies are fiercely debated following the Copenhagen conference in December 2009, including the merits of a general carbon tax, whether  a cap-and-trade scheme should apply generally or to power generation only, and whether policies should be directed toward individual carbon-intensive industries. The equity criterion is even more complex, because it has to recognize differences in incomes, both within and between nations, different access to technologies, and not least the impact of historical responsibility – notably that the developing world is being dealt a double whammy: poor countries are least responsible for the existing stock of greenhouse gases (though China, India*,* Brazil and Indonesia are catching up fast), but they are hit earliest and

[65] But Garnaut (2008) suggests that non-market factors such as environmental amenity may offset the impact of greater income and wealth. There is also an inherent flaw in the argument if world economic growth is at serious risk of becoming reversed in a warming world – the possibility demonstrated in Appendix 4.

hardest by climate change. Stern notes: "The rich countries have major historical and other responsibilities, and must show leadership. Without it, global action must fail." (p 13)

***The cost of inaction***

Economists who have been involved in the analysis of climate change agree that the cost of tackling climate change now is moderate, and looked at in a long-term perspective makes no real difference in the future income flow of a country. The same economists, notably Stern and Garnaut, agree also that inaction can lead the world into a very difficult situation from which there may be no way back. (BAU) scenarios are being increasingly seen as courting catastrophe. The three items in the bottom of Figure 3 summarize this.

## GENUINE INTERDISCIPLINARY INFLUENCES

The approach to economic modeling offered by some scientists and touched upon in the section headed 'scientists offer to re-define economic theory' underestimates the quality and solidity of economic theory that has developed over the past two centuries or more. Economics is much more than predicting "bubbles and busts"; but econophysics may also be developing into an integral branch of *complexity theory*, as reported below.

Attempts by scientists to "help" economists in the belief that the "bubbles and busts" arena is the only central economic theory are very different from the real opportunities for the physical and behavioral sciences to develop and support one another, extending to "even … the arts and humanities" as 1969 Nobel Physics Prize winner Murray Gell-Mann observed in *The Quark and the Jaguar* in 1994.[66] Complexity theory is discussed below.

### COMPLEXITY THEORY AND COMPLEXITY ECONOMICS

***The role of a genuine interdisciplinary philosophy***

Complexity theory has experienced a renaissance since the founding in 1984 of the Santa Fe Institute in New Mexico. Its influence may well be further absorbed into economic theory because of the perceived shortcomings of traditional economics in dealing with climate change and the economic and financial crisis. Complexity theory applied to economics is part of the attempted synthesis of a possible future economic paradigm outlined at the end of the appendix.

The theory originated in a scientific and engineering context during the immediate postwar years with the blossoming of the modern form of *cybernetics*, the interdisciplinary study of regulatory systems which formalized the notion of feedback and developed a wide range of applications from engineering, systems control, computer science, and biology, to philosophy and the organization of society.

[66] An unpublished manuscript for the Australia Council for the Arts, *The Arts on the Edge of Chaos*, was to a large extent inspired by complexity theory (Letts 1995). The last chapter, "Culture and the Biosphere", refers to Gell-Mann's observation (1994) that we now have the capacity to destroy the biosphere, "whether deliberately or as a side effect of other activities." (p 213) Letts ponders what artists can contribute, noting: "Since biological evolution cannot cope, and since the problem originates with humanity, the only hope lies in a benign cultural evolution." These thoughts are remarkable in a 15-year old script, given that the threat to the planet's ecosystems has become greatly aggravated since 1995.

The work of British biologist and anthropologist Gregory Bateson across the fields of cybernetics (including information, communications and systems theory) was an important influence for many social and behavioral scientists who were first introduced to cybernetics by Bateson (Bale 1995). An important element of his work was his ecological philosophy, not at all common when he formulated it around 1970. "We are beginning to play with ideas of ecology, and although we immediately trivialize these ideas into commerce or politics, there is at least an impulse still in the human breast to unify and thereby sanctify the total natural world, of which we are." (Bateson 1979)

Complexity economics is the application of complexity science to the problems of economics. Complexity has become the last of the "four C's" of a new paradigm surfacing in the field of economics: cybernetics (1950s and '60s), catastrophe (1970s), chaos (1980s), and complexity (1980s to date), all governed by nonlinear dynamics and positive feedback processes. The new mode of economic thought queries the traditional neoclassical assumptions that imply that the economy is a closed system that eventually reaches an equilibrium. It views economies as open complex adaptive systems with *endogenous* evolution, including *endogenously generated technologies* to provide dynamic growth.[67]

In contrast, the neoclassical economic growth model pioneered by Solow (1956) treated the generator of growth, technology, as exogenous. Romer (1990) was the first to introduce a growth model in the neoclassical tradition with an endogenous technological driver. This, however, ignores Joseph Schumpeter, born in the same year as John Maynard Keynes (1883) and sometimes seen as his rival. As a young economist he wrote the German-language version of his *Theory of Economic Development* in 1911, which he revised in 1926 and which was translated into English in 1934. It divided economic processes into three different parts (as described by Elliott (1983) in his introduction to a new edition of Schumpeter's book):

1. In the absence of economic development, the competitive capitalist economy is reduced to a routine of maintaining the "circular flow" (*Kreislauf* in the German version) in a stationary general equilibrium. The economy would move along a stable equilibrium growth path, determined by small and gradual increases in the labor force, savings, and capital accumulation. There would be no entrepreneurs, only businesses reacting passively to changing market demand and cost structures. The "sovereign consumer" of classical and neoclassical economic theory would be king and queen.
2. The economic development comes from far within the economic system – it is an *endogenous* force and not merely a reaction to external stimuli. It occurs discontinuously, and it brings qualitative changes or "revolutions" which fundamentally displace old equilibria and create radically new conditions. It is accompanied by growth from sustained upward movements in national income, savings, and population. The development of the railroads in the 19th century and the automobile in the 20th emerged from the entrepreneurs in the commercial and industrial sectors of the economy, and not at all from the "sovereign consumer" of classical economics.

[67] http://en.wikipedia.org/wiki/Complexity_economics, accessed September 2009). See further Appendix 6.

3. The third part is those economic processes that impede the undisturbed course of development.

A subsequent book by Schumpeter (*Capitalism, Socialism and Democracy*, 1943) contains a concise explanation of his economic view and his concept of *creative destruction*, which he called "the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in." See Addendum 2 to this appendix.

The main commentator on the "four C's" appears to be Rosser (1999). A few years previously, science journalist John Horgan had branded them a series of "failed fads", in opposition to the opinions within the Sante Fe Institute. Rosser takes a more positive view while conceding that it was still difficult when he wrote to identify a concrete and surprising discovery that had arisen due to the emergence of complexity analysis.

"Rather, complexity theory has shifted the perspective of many economists towards thinking that what was viewed as anomalous or unusual may actually be the usual and expected, especially in the realm of asset markets where the unusual seems increasingly commonplace! Indeed, there is a strain of common perspective that has been accumulating as the four C's of cybernetics, catastrophe, chaos and complexity emerged, which may now be reaching a critical mass in terms of influencing the thinking of economists more broadly." (p 187)

Catastrophe theory emerged during the 1970s. A catastrophe is a particular kind of discontinuity in a dynamic system. The discontinuities depend on distinct multiple equilibria and involve jumping from one to another as some control parameter gradually changes. Catastrophe theory generated an even greater multidisciplinary "fad" than did cybernetics, according to Rosser (p 172). Indeed, modeling discontinuities continues to be a major theme of more recent complexity models.

Chaos theory studies the behavior of dynamic systems that may be highly sensitive to initial conditions. Tiny differences in the starting state of the system can lead to enormous differences in the final state of the system even over fairly small timescales (popularly referred to as the "butterfly effect" – "a butterfly flapping its wings in Texas may cause a tornado in the Philippines"). Economists used chaos theory in the 1970s, but it became widely known through a best-selling book (Gleick 1988), which successfully explained the many aspects of the theory including esoteric matters such as the apparent ability of so-called fractals to reproduce themselves in ever-decreasing sizes in chaotic systems.

One term that became widely used in several disciplines in the 1990s was the "edge of chaos". The term was coined in 1990 by scientists associated with the Santa Fe Institute to deal with the highly mathematical properties of models called cellular automata.[68] However, the phrase quickly came to refer to a metaphor that some physical, biological, economic and social systems operate in a region between order and complete randomness or chaos, where the complexity is maximal. Figure 4 (redrawn from Beinhocker (1997)) shows "the edge of chaos" as the critical transition point between order and complete randomness or

[68] http://en.wikipedia.org/wiki/Cellular_automaton.

chaos, where the complexity reaches its maximum. The description below the graphic is Beinhocker's.

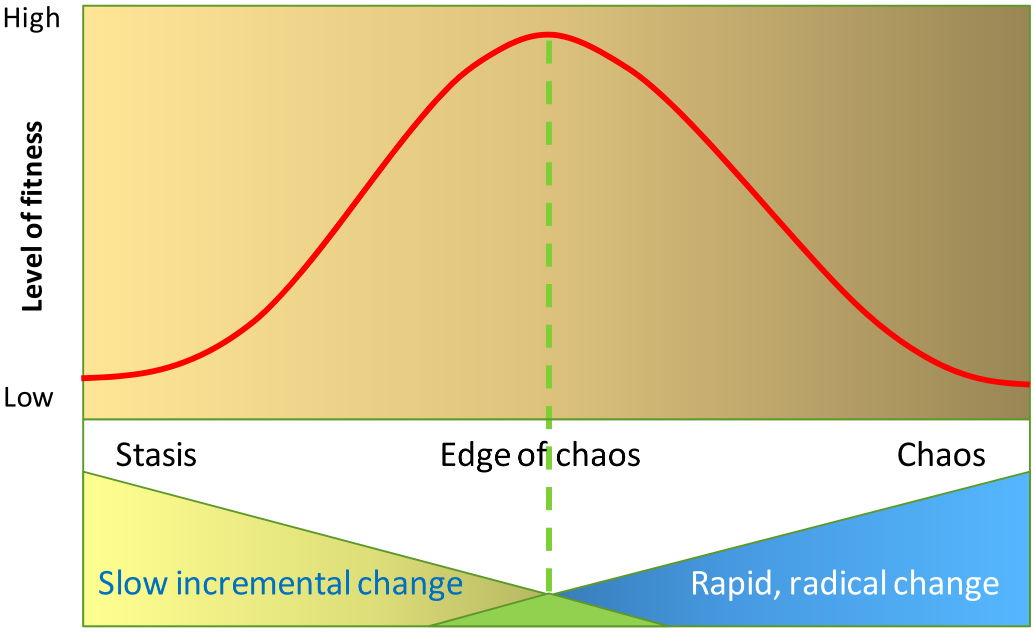



*Figure 4: The edge of chaos. In a complex adaptive system, an agent that is resistant to change and not adaptable will have low fitness, and so, conversely, will an agent that is oversensitive to shifts in its environment and constantly making radical responses. But between these extremes of stasis and chaos lies a region – the edge of chaos – where fitness is maximized. Being at the edge of chaos means something more subtle than pursuing a moderate level of change. At the edge of chaos, one is simultaneously conservative and radical. Adapted with acknowledgments from Beinhocker (1997).*

Whether or not the "three C's" described above became faddish through overuse or misuse is not our concern here. Many see complexity as a newer and higher stage of analysis, distinct from the previous "C's" of cybernetics, catastrophe, and chaos (Rosser 1999, p. 176). No tight definition exists, but speaking from the "Santa Fe perspective" W. Brian Arthur, Steven Durlauf and David Lane (1997) suggested that the following features identified in complexity economics present difficulties for the traditional mathematical models used in economics. Systems with these properties have come to be called *adaptive nonlinear networks*:

- **Dispersed interaction**: What happens in the economy is determined by the interaction of many dispersed, possibly heterogeneous, agents acting in parallel. The action of any given agent depends upon the anticipated actions of a limited number of other agents and on the aggregate state these agents co-create.
- **No global controller**: No global entity controls interactions. Instead, controls are provided by mechanisms of competition and coordination between agents. Economic actions are mediated by legal institutions, assigned roles, and shifting associations. Nor is there a universal competitor – a single agent that can exploit all opportunities in the economy.

- **Cross-cutting hierarchical organization**: The economy has many levels of organization and interaction. Units at any given level of behaviors, actions, strategies, products typically serve as `building blocks' for constructing units at the next higher level. The overall organization is more than hierarchical, with many sorts of interactions (associations, channels of communication) across levels.
- **Continual adaptation**: Behaviors, actions, strategies, and products are revised continually as the individual agents accumulate experience – the system constantly adapts.
- **Perpetual novelty**: Niches are continually created by new markets, new technologies, new behaviors, new institutions. The very act of filling a niche may provide new niches. The result is ongoing, perpetual novelty.
- **Out-of-equilibrium dynamics:** Because new niches, new potentials, new possibilities are continually created, the economy operates far from any optimum or global equilibrium. Improvements are always possible and indeed occur regularly.

***Inspiration from polymaths***

The multidisciplinary quality applies not only to the general approach to complexity but also to many of its practitioners who are true polymaths. Their broad orientation has helped substantially to make complexity a genuine influence across a wide range of disciplines.

Among the persons active in the Santa Fe Institute, *Murray Gell-Mann* is a physicist specializing in elementary particles (he is famous for finding and naming the quark as a pivotal building block in his hierarchy of subatomic particles which earned him the Nobel Prize in 1969), but according to his Nobel Prize biography,[69] "Gell-Mann's interests extend to historical linguistics, archeology, natural history, the psychology of creative thinking, and other subjects connected with biological and cultural evolution and with learning. Much of his recent research at the Santa Fe Institute has focused on the theory of complex adaptive systems, which brings many of those topics together."

*William Brian Arthur* also has broad professional qualifications. His undergraduate degree was in electrical engineering, followed by two M.A.s in operations research and mathematics, respectively. He obtained his Ph.D. in operations research in the same year (1973) that he took an M.A. in economics. At 37 (1982) he became the youngest endowed professor at Stanford University, in economics and population studies. Arthur has had great influence on the development of complexity economics, and complexity theory generally, at the Santa Fe Institute with which he remains associated as an External Professor, as well as being a Visiting Researcher at the Palo Alto Research Center for commercial innovation (PARC). He was joint winner of the Schumpeter Prize in Economics in 1990, when the theme for the prize was evolutionary economics. In 2009 he was joint winner of the inaugural $110,000 Lagrange Prize in Complexity Science. [70]

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[69] http://nobelprize.org/nobel_prizes/physics/laureates/1969/gell-mann-bio.html.

[70] Arthur in 2009 wrote an important book on the evolutional nature of technology, which forms the basis for the discussion in Appendix 6. Apart from Darwin (12), Schumpeter has the largest number of index references (9).

*Herbert A. Simon*, who was awarded the Nobel Prize in Economics in 1978 for his pioneering research into the decision-making process within economic organizations, was perhaps the greatest polymath of them all – an American economist and psychologist (with a Ph.D. in political science) whose research ranged across the fields of cognitive psychology, computer science, public administration, economics, management, philosophy of science and sociology. He was the Richard King Mellon Professor of Computer Science and Psychology at Carnegie Mellon University in Pittsburgh, Pennsylvania, where he taught for 52 years.

Simon was among the founding fathers of artificial Intelligence, information processing, decision-making, problem-solving, attention economics, organization theory, complex systems, and computer simulation of scientific discovery. He was the first to analyze the architecture of complexity (Simon 1962). As well as receiving the highest honor possible in economics, he was the recipient of the American Psychological Association's Award for Outstanding Lifetime Contributions to Psychology in 1993, and the prestigious A. M. Turing Award for his work in computer science (1975). [71]

***Parallels in traditional science and traditional economics***

Science has a traditional orientation that has proven extraordinarily successful. Scientists have historically taken a top-down, reductionist approach in which the universe is broken into ever-smaller pieces in search of ultimate laws, from the level of galaxies to subatomic particles. Many of the hardest problems in nature, however, are "complex systems" that have collective or emergent characteristics that are better understood through a bottom-up, holistic approach (Beinhocker 2006). Ecology and climate science are on top of that list.

Economics faces a different dilemma, due to its focus on abstract rather than observable entities. The traditional approach has dominated economic theory for a century and remains the frame of reference in most university textbooks, and for the media, business and government. Though economists are more prone than scientists to build their theory on assumptions such as "rational economic man" and other artificial concepts of neoclassical equilibrium economics, it would be monumentally wrong to reject the discipline. No responsible economist would contemplate such a step. Its main weakness is parallel to the reductionist approach in science, and can be supplemented in similar fashion through holistic, bottom-up approaches. The economics as well as the science of climate change exemplifies this. Brian Arthur remarks: "The result, complexity economics, is not an adjunct to standard economic theory, but theory at a more general, out-of-equilibrium level." (Arthur 1990, p 107) [72]

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[71] http://en.wikipedia.org/wiki/Herbert_Simon.

[72] This article, in *Scientific American*, is concise but not the ultimate paper Arthur wrote in 1989, in which he developed the concepts of positive feedback and increasing returns. In an interview with Jaworski et al. (1999) he said that "if there was a moment of epiphany, it was in June 1979 when I read a little essay that [Russian/Belgian physical chemist and Nobel Laureate Igor] Prigogine had written. I forget what he called it, … but it was about positive feedback, and instantaneously I realized I had something that was important in economics. All I needed to do was figure out how positive feedbacks worked in economics, and it took another ten years to do that. But suddenly, within about two or three weeks, everything in economics fell into place for me. It was a period of very, very intense intellectual excitement." The paper was eventually published in *The Economic Journal* (Arthur 1989).

***The Santa Fe Institute***

The Institute describes itself as "devoted to creating a new kind of scientific research community, one emphasizing multi-disciplinary collaboration in pursuit of understanding the common themes that arise in natural, artificial, and social systems. .. The Santa Fe Institute is a private, not-for-profit, independent research and education center founded in 1984, for multidisciplinary collaborations in the physical, biological, computational, and social sciences. Understanding of complex adaptive systems is critical to addressing key environmental, technological, biological, economic, and political challenges. Renowned scientists and researchers come to Santa Fe Institute from universities, government agencies, research institutes, and private industry to collaborate in attempts to uncover the mechanisms that underlie the deep simplicity present in our complex world.[73]

The last part of the statement is a reflection on co-founder Murray Gell-Mann's *Quark and the Jaguar* (1994), which sets forth his "views on an emerging synthesis at the cutting edge of inquiry into the character of the world around us – the study of the simple and the complex." (p ix)

Beinhocker (2006) writes: "The group had set itself the modest ambition of fundamentally changing the way in which scientific research is conducted." The view was that the reductionist approach to scientific research had to be urgently supplemented with the bottom-up, holistic perspective mentioned in the previous section.

Economics entered soon after the foundation of the Santa Fe Institute. As Beinhocker (2006) tells the story, John Reed at 45 in 1984 had just been elected chairman and CEO of Citicorp, a banking company that had recently been through a major trauma. Like other banks, it had lent aggressively to Latin American and other governments in the 1970s. This had been regarded as "safe banking" because governments did not default on their debts. But Mexico did so in 1982.

Reed could not understand why the best brains at Citicorp and the other major banks so badly misjudged the risks. He consulted leading economists from academia, Wall Street and the government, but they apparently had few insights to add about the crisis.

Having got in contact with the Santa Fe scientists, Citicorp in 1987 agreed to fund a cross-disciplinary workshop with a group of 10 leading economists invited by famed general equilibrium theorist and Nobel Prize winner Kenneth Arrow. They included Larry Summers who went on to become Treasury Secretary in the Clinton administration and more recently Director of President Obama's National Economic Council. The line-up of 10 scientists who also participated was no less impressive.

The meeting resulted in the founding, in 1988, of the Economics Program at the Santa Fe Institute, the Institute's first resident research program. Most important for the subsequent development, W. Brian Arthur, who remains associated with the Institute, was another member of the group of 10 economists. He has probably done more than any other individual to develop complexity economics.

[73] http://www.santafe.edu/.

His research into positive feedback in dynamic economic models (Arthur 1989, 1990) shows an important way forward. Conventional economics, he says, is based on diminishing returns, which means that economic actions eventually engender a negative feedback that leads to a predictable equilibrium for prices and market shares. Negative feedback tends to stabilize the economy because any major changes will be offset by the very reactions they generate. But this may not tell the real story.

"In many parts of the economy, stabilizing forces appear not to operate. Instead, positive feedback magnifies the effect of small economic shifts; the economic models that describe such effects differ vastly from the conventional ones. Diminishing returns imply a single equilibrium point for the economy, but positive feedback – increasing returns – make for multiple equilibrium points. There is no guarantee that the particular economic outcome selected from among the many alternatives will be the "best" one. Furthermore, once chance economic forces select a particular path, it may become locked in regardless of the advantages of other paths."

This view of positive feedbacks is strongly connected with technological change. Although there is no guarantee that the best technology wins out,[74] "technologies typically improve as more people adopt particular technology, the more it improves, and the more incentive there is for further adoption." He concludes: "With the acceptance of positive feedbacks, economists' theories are beginning to portray the economy not as simple but complex, not as deterministic, predictable and mechanistic, but instead as process-dependent, organic and always evolving." (Arthur 1990)

***Expanding econophysics?***

This question needs to be addressed – although with some reservations – because it is being quite vigorously pursued, and has links to complexity theory and the Santa Fe Institute. Econophysics is also associated with the dominant mathematical school of neoclassical economics, including its genesis in works such as Samuelson's *Foundations of Economic Analysis* from 1947 which the author stated was inspired by physical science (Samuelson 1998). The pendulum appears to have swung toward greater affinity with biology and ecology than with physics. This is discussed further in the beginning of the next main section: "What might this mean for economics in the future?"

The journal *Complexity* in 2008 devoted a full issue to the subject of econophysics, which is related to complexity economics though the latter term implies a broader scientific input. It was edited by the well-known mathematical economist Martin Shubik (one of the fathers of game theory back in the 1950s) and physicist Eric Smith. Both are currently associated with the Santa Fe Institute, as were several of the contributors to the issue (physicist Doyne Farmer and economist John Geanakoplos writing about the future of financial markets , and physicist Fabrizio Lillo).

[74] One very large example of conflicting technologies from which the best outcome probably failed to eventuate, even ignoring the resulting climate change, would be the battle between electric and gas-driven cars in the early part of the 20th century described by Edwin Black in *Internal Combustion* (2006).

Lillo (2009) puts the rise of econophysics in the context of the more general interest of physicists and other scientists towards complex systems. He thinks there are at least "three topics in which econophysics could give interesting insights and therefore are more likely to develop. First, up to now econophysics has been strongly biased toward finance. A progressive shift of econophysics toward other branches of economics different from finance is certainly desirable. Macroeconomics, for example, is a field where the interaction between physicists and economists has been quite sporadic." (p 53) It may be argued that Paul Samuelson's seminal treatise in 1947 helped trigger the dominance of mathematical economics, related to principles originating in physics.

Secondly, however, Lillo feels econophysics has made a useful contribution in the area of finance and should be encouraged to continue to do so. "As for the third topic, the recent availability of large data-sets on the behavior of individuals in different socioeconomic systems will open up the development of a new type of agent based modeling. In this modeling, the output from empirical analyses on agent's behavior will be used as an input for agent based modeling, which in turn can give insight on the empirical facts (and the type of data) to look at. This synergic interaction between modeling and empirical analysis … is in my opinion the most challenging playground for the dialogue between physics and economics." (p 53)

Farmer and Geanakoplos (2009) set out "to convince the skeptics that equilibrium models can be useful, but also to make traditional economists more aware of the limitations of equilibrium models." (p 11) Equilibrium theory "is an elegant attempt to find a parsimonious model of human behavior in economic settings. It can be criticized, though, as a quick and dirty method, a heroic attempt to simplify a complex problem. Now that we have begun to understand its limitations, we must begin the hard work of laying new foundations that can potentially go beyond it." (p 34)

The focus in the Farmer and Geanakoplos paper is the general equilibrium theory of Arrow and Debreu (1954), based on the assumptions of perfect competition (price taking); that agents always optimize their utility within the limitations of the model; on market clearing to maintain equilibrium at all times; and on rational expectations based on perfect information. The model showed that there "always is an equilibrium, no matter what the endowments and technologies and utilities, provided that each utility displays diminishing marginal utility of consumption and each technology displays diminishing marginal product." (p 13)

The subjects in these papers remain biased towards financial markets. This is in the very title of the Farmer and Geanakoplos paper, as well as Lillo (2009), which focuses on the efficient market hypothesis, a "cornerstone in economics" stating that a market in which prices always fully reflect available information is "efficient**".** Shubik and Smith (2009) conclude their review of the papers in the special issue of *Complexity* (p 10):

"The perspective from these reviews is that much progress has been made, especially in data-rich applications in domains such as finance. These are not merely gains in method; natural-science modes of data interpretation and model validation are impacting core concepts about market function. At the same time, many questions of fundamental interest to economists are not reflected in this work, and whether they fit within the methodology of natural as well as social science remains an open question. At least, for the present, the answer is not clearly “no.” “

One interesting parallel with what has been previously noted in climate models (the fat-tail analysis by Weitzman (2009)) is the occurrence of heavy-tailed distributions in price series, income and wealth distributions, and other social phenomena. “These “excesses” of rare

| Aspect | Complexity Economics | Traditional Economics |
|---|---|---|
| Dynamic | Open, dynamic, non-linear systems, far from equilibrium | Closed, static, linear systems in equilibrium |
| Agents | Modelled individually; use inductive rules of thumb to make decisions; have incomplete information; are subject to errors and biases; learn to adapt over time; heterogeneous agents | Modelled collectively; use complex deductive calculations to make decisions; have complete information; make no errors and have no biases; have no need for learning or adaptation (are already perfect), mostly homogeneous agents |
| Networks | Explicitly model bilateral interactions between individual agents; networks of relationships change over time | Assume agents only interact indirectly through market mechanisms (e.g. auctions) |
| Emergence | No distinction between micro/macro economics; macro patterns are emergent result of micro level behaviours and interactions. | Micro-and macroeconomics remain separate disciplines |
| Evolution | The evolutionary process of differentiation, selection and amplification provides the system with novelty and is responsible for its growth in order and complexity | No mechanism for endogenously creating novelty, or growth in order and complexity |
| **Technology** | Technology fluid, endogenous to the system | Technology as given or selected on economic basis |
| **Preferences** | Formulation of preferences becomes central; individuals not necessarily selfish | Preferences given; Individuals selfish |
| **Origins from physical sciences** | Based on biology (structure, pattern, self-organized, life cycle) | Based on 19th-century physics (equilibrium, stability, deterministic dynamics) |
| **Elements** | Patterns and possibilities | Price and quantity |

Source: Wikipedia (http://en.wikipedia.org/wiki/Complexity_economics, accessed 4 September 2009).

*Figure 5 illustrates the differences between the complexity perspective and classical economics. Eric Beinhocker (2006) proposed five concepts that distinguish complexity economics from traditional economics. The first five categories are Beinhocker's synthesis, the last four are from W. Brian Arthur as reprinted in Colander (2000).*

events have pointed, perhaps more than any other quantity, to inadequacies of equilibrium theories, and have provided much of the support for ideas drawn from natural sciences to study them. **“** This parallel with climate-change economics would be worth pursuing.

***Traditional versus complexity economics***

Figure 5 is reproduced from Wikipedia’s description of complexity economics; the anonymous contributor is gratefully acknowledged. The top five items were derived from Beinhocker (2006), the bottom four from W. Brian Arthur’s work. The items speak for themselves but it is useful to read them in conjunction with the previous six-point description of adaptive nonlinear networks (Arthur et al. 1997).

***Constructively dissident economic voices are not a new phenomenon***

The time may have been right for complexity theory to start influencing economics in the 1990s, but highly reputable mainstream economists have tried for decades to challenge the assumptions of the “neoclassical paradigm with its fundamental notions of rational, optimizing consumers making choices in a world of finite resources.” (Beinhocker 2006)

Within a limited space, the evidence presented here cannot be encyclopedic. We can only deal with relatively recent examples of challenges to neoclassical economics. The following case is considered representative in addition to Brian Arthur’s direct influence on complexity economics and Herbert Simon’s work on ‘satisficing’ and other modifications – not to mention the identification of animal spirits by Keynes himself, and Schumpeter’s insights which includes the basic role of technology as an endogenous economic driver. We add that Leijonhufvud’s paper quoted below shows him to be well aware of the then emerging complexity economics; indeed, he was a contributor to Arthur et al. (1997), which contains the proceedings of a Santa Fe Institute workshop in 1996.

Back in 1950, UCLA economist Armen A. Alchian wrote what became a classical paper titled *Uncertainty, Evolution, and Economic Theory.* He stated in his introduction (Alchian 1950, p 211):

“The suggested approach embodies the principles of biological evolution and natural selection by interpreting the economic system as an adoptive mechanism which chooses among exploratory actions generated by the adaptive pursuit of "success" or "profits." The resulting analysis is applicable to actions usually regarded as aberrations from standard economic behavior as well as to behavior covered by the customary analysis. This wider applicability and the removal of the unrealistic postulates of accurate anticipations and fixed states of knowledge have provided motivation for the study.”

Forty-odd years later, a younger UCLA colleague, Axel Leijonhufvud, envisaged a “not-too-rational macroeconomics” inspired by Alchian (Leijonhufvud 1993). He quoted a friend saying that “practical men of affairs, if they know anything about economics, often distrust it because it seems to describe the behavior of *incredibly smart people in unbelievably simple situations.*” He noted, however, that “standard economic theory is useful in a myriad ways, despite its unrealistic assumptions about people's cognitive capabilities, because the interaction of ordinary people in markets very often does produce the incredibly smart result. When it does, it can be a convenient short-cut to model the social interaction process as if it was planned (and policed) by a representative agent or social planner possessed of rather superhuman abilities." (p 2)

So the rationalist model may work despite the limited knowledge of its agents, but it is by no means certain as Leijonhufvud duly notes in his conclusion (quoted below).

Alchian advocated a method "very much at variance with the one that dominates macrotheory today, a method ... which treats the decisions and criteria dictated by the economic system as more important than those made by the individuals in it." Leijonhufvud notes that efficiency, in the Alchian model, "stems less from the ex ante rational planning of typical economic agents than from the ex post elimination through competition of ill-adapted modes of behavior. We might start, then, by asking how *believably simple people cope with incredibly complex situations*. If we knew a bit about that, we could then go on to study the conditions under which market interaction will and will not configure the complex system into that incredibly smart allocational pattern. Because, of course, social interaction does not always produce the perfectly rational result. Sometimes, as James Tobin once said, "the invisible hand is nowhere to be seen." Ordinary people also interact to produce booms and busts in real estate, credit crunches and bank panics, great depressions and hyperinflations – and much other misery besides." (p 2)

Leijonhufvud concludes (p 12):

"To understand what is actually going on, I strongly believe, one must abandon this entire mode of theory construction and rethink the matter from Alchian's evolutionary perspective. Here believably simple people face incredible complications and, finding themselves unable to precalculate the consequences, give up trading in most future markets. New externalities appear where price-interaction has withered away. As coordinating mechanisms disappear, imperfect decision-makers no longer face the same Darwinian pressures to adapt. Potential gains from trade are left unexploited. Various inefficient practices survive. Resources fail to find their highest valued uses. The difference between the two approaches matters. The rationally expectant optimizers of today's standard theory do not need market interaction to teach them how to attain the efficient social outcome. Alchian's imperfect decision-makers do. But an Alchian market-process is not an aggregate of mutually consistent optimal decisions. So, it cannot be modeled in the standard way. But I believe we can do it in the computable way."

The last remark is a reminder that neoclassical economics was formulated when computers were in their infancy rather than in 1993 when Leijonhufvud felt encouraged to believe in computer power. The macro-econometric models of the immediate postwar years involved less than 10 stochastic[75] equations. The Klein interwar model of the United States economy over the period 1921-41, published in 1950, involved three stochastic and three non-stochastic equations in six endogenous and four exogenous variables. A celebrated model of the U.S. economy from 1929-41 and 1946-52, Klein-Goldberger from 1955, involved 15 stochastic and five non-stochastic equations in 20 endogenous and 14 exogenous variables. (Intriligator 1983, p 205)

[75] Random variables were included, typically as additive stochastic disturbance terms, to account for omission of relevant variables, incorrect model specifications, and errors of measurement (Intriligator 1983, p 187).

## BEHAVIORAL ECONOMICS AND THE POTENTIAL CONTRIBUTION FROM PSYCHOLOGY

Within the behavioral sciences, there is a natural affinity between economics and psychology, which has recently returned to prominence through publications like Akerlof and Shiller's *Animal Spirits*, and also through a recent report by an American Psychological Association task force on psychology's potential contribution to combating climate change.

Behavioral economics is related to neuroeconomics, indicating that some branches of economics are reaching out to the biological and medical sciences. Money illusion, for example, has been shown to be associated with a specific site in the pre-frontal cortex of the brain (Stix 2009).

The founder of modern behavioral economics, Daniel Kahneman, noted in his Nobel Prize address in 2002 that his paradigm differed from the traditional version (Kahneman 2003): "Theories in behavioral economics have generally retained the basic architecture of the rational model, adding assumptions about cognitive limitations designed to account for specific anomalies. For example, the agent may be rational except for discounting hyperbolically, evaluating outcomes as changes, or a tendency to jump to conclusions.

The model of the agent that has been presented here has a different architecture, which may be more difficult to translate into the theoretical language of economics. The central characteristic of agents is not that they reason poorly but that they often act intuitively. And the behavior of these agents is not guided by what they are able to compute, but by what they happen to see at a given moment."

This seems to fit the animal spirits model well. However, despite Kahneman's undoubted influence in both disciplines it is difficult to find positive links where psychological insights are of great benefit for macroeconomic analysis, specifically in the area of climate change.[76] The American Psychological Association task force report (Swim et al. 2009) addresses how psychologists can assist in limiting climate change:

"Climate change now occurring globally is driven by a variety of human actions. The proximate causes include burning fossil fuels, clearing forests, raising cattle, and other actions that release greenhouses or change the reflectivity of Earth's surface. These actions in turn result from other human activities, including government policies, population increases and migrations, economic development activities, and the behavior of individuals and households as consumers, members of organizations, and citizens – and in turn from underlying human attitudes, predispositions, social and economic structures, and beliefs.

[76] Behavioral economics seems to have taken on a better hold at the microeconomic level (Lovallo and Sibony 2010). "Once heretical, behavioral economics is now mainstream. Money managers employ its insights about the limits of rationality in understanding investor behavior and exploiting stock-pricing anomalies. Policy makers use behavioral principles to boost participation in retirement-savings plans. Marketers now understand why some promotions entice consumers and others don't." The authors present a typology to identify cognitive bias such as excessive optimism, overconfidence, competitive neglect, and interest biases such as misaligned individual incentives and disagreements (often unspoken) about the objectives pursued by the organization and the tradeoffs between them. Such biases at corporate management level would have their aggregate counterparts, fitting into the broad realm of animal spirits.

Psychological science would seem indispensible for understanding and finding ways to change at least some of these human behaviors. Nevertheless, psychologists have rarely been consulted by climate policy decision makers." (p 136)

They don't seem to have peddled their services much either. The APA report comes across in a somewhat abstract way without an apparent attempt to define how the contribution of psychology could be integrated with other disciplines, notably economics. Delving into the report, Aldhous (2009) reviews some "tricks that could be deployed by companies or organizations to encourage climate-friendly behavior." The following may represent some of the more promising avenues:

- Most people want to be good neighbors and fit in with the crowd, which psychologists exploit to encourage environmentally friendly behavior.
- Some domestic appliances and cars display energy usage and savings, which helps provide incentives for using less.
- Some psychological research aims at persuading people to act on climate change even though the benefit won't be felt for decades. For instance, schemes that give people an upfront cash payment for insulating their home will work better than those promising long-term savings, even if the people receiving cash end up paying a little more in the long run.
- People are social animals who like to interact with others and take inspiration from their actions. Psychologists are working out how to exploit this to spread behaviors that will help limit climate change. The lead author of the APA report, Janet Swim, says, "My sense is that social networks are going to be important."

Social psychologist Mark van Vugt (2009) reports on interdisciplinary research into how people across cultures interact with nature and how it affects their wellbeing. This could lead to the triumph – rather than the tragedy – of the commons. Famous Harvard biologist Edward O. Wilson coined the term *biophilia* (in a book of the same name published in 1984) to describe the idea that we have a basic need to enjoy and affiliate with nature. Van Vugt comments: "If it turns out to be hard-wired, the biophilia could be another strong motivator in persuading people to protect the environment." (p 41) There are echoes here of Bateson's 40-year-old ecological philosophy.

The APA report and van Vugt's observations suggest that one important potential contribution from psychologists is the role of altruistic behavior. Graeme Taylor's observation in Appendix 3 that women's rights, peace, social justice, and the environment represent four growing areas of societal change suggests that there are countervailing forces to economic selfishness – businesses too are demonstrating large-scale altruistic behavior. A cynic might dismiss this, and the role of ethics in the Stern and Garnaut reports on climate change, and the Millennium Goals to eliminate poverty, as survival mechanisms. It would be vastly preferable to contemplate how these positive psychological behaviors might be mobilized in the fight against climate change.

To help achieve this, the bond between the sister disciplines of psychology and economics needs to be nurtured and developed, especially as far as the direct contribution of mainstream psychology is concerned. Kahneman's and Simon's influence has been through direct input into economic thinking from their dual academic backgrounds in economics and psychology, but direct cooperation between the two disciplines on specific issues such as climate change still seems to be some distance off.

The APA report notes (Swim et al. 2009, p 138): "Policy makers are increasingly coming to recognize that the dominant physical-technical-economic model of energy use is incomplete and are turning to behavioral scientists for better conceptual models and for advice on how to implement them so as to make policies and programs more effective." While it is not yet very visible, the APA's initiative in putting a task force together specifically on climate change is laudable, and may lead to more advanced analysis of what psychologists can contribute on their own and in cooperation with economists.

## WHAT MIGHT THIS MEAN FOR ECONOMICS IN THE FUTURE?

### ANIMAL SPIRITS AND MARKET FAILURES

The analysis of "animal spirits" revived by Akerlof and Shiller (2009) is an important contribution which deals directly with the sources of the global economic and financial crisis precipitated by the Lehman Brothers failure in September 2008. It lists the animal spirits responsible as *confidence*, *fairness*, *corruption and bad faith*, *money illusion*, and *stories*. They cause the business cycle to fluctuate more violently than if people had acted "rationally" at all times – the assumption which appears to encapsulate the major weakness of conventional economic theory.

Animal spirits also play a prominent part in the research into the need for an uncertainty principle in economics (Ball 2010). The current "taxonomy of uncertainty" at the MIT Sloan School of Management under Andrew Lo is important in this respect, because it helps in determining how far economic models are useful and where they fail (Lo and Mueller 2010, Brennan and Lo 2009). Lo and his colleagues hope it will be possible to extend the analysis to incorporate the "irrational" animal spirits, given greater knowledge and greater computational power. They also point to the need for economics to reduce its need for mathematical models inspired by physics, in favor of inspirations from biology (including evolutionary biology), ecology, and meteorology.

The uncertainty principle is of obvious relevance to climate change. In this respect, the alleged failure of economists to recognize "fat-tailed" probability distributions – giving more weight to extreme values than the normal Gaussian distribution – is highly important (Ball 2010). While the MIT work focuses on commodity prices, Weitzman (2009) and others have shown that the uncertainty and risk associated with accelerating climate change has similar characteristics.

The next question, which is related to the previous paragraph, is: are "animal spirits" also involved in the emerging economics of climate change and its causes? The two main books under review here don't provide explicit guidance. Akerlof and Shiller never mention Stern's central concept of market failure, and Stern makes no reference to Keynesian animal spirits. The answer, however, is yes.

Market failure is failure of the price mechanism. Manufacturers of products dependent on fossil fuels for energy or raw materials have paid little or nothing for polluting the atmosphere and oceans. As a result, major renewable energy technologies were delayed for decades and without corrective action remain generally uncompetitive with fossil fuels.

This situation has almost certainly eventuated as a result of a long history of animal spirit activities. In his book *Internal Combustion*, Edwin Black (2006) tells the story of how America in the early 20$^{th}$ century seemed well on the path towards electric motor vehicles, with Thomas Edison and Henry Ford collaborating to mass-produce electric cars powered by personal backyard energy stations. But petroleum interests effectively set the path that favored the internal combustion engine, with General Motors as a key player. The story invokes plenty of animal spirits and Black himself says that the book is about greed and deception. The resulting market failure appears to have been caused mainly by sheer abuse of power, plus the unfortunate fact that Edison's laboratory complex was destroyed by fire at the crucial time which seems to have finally set the internal combustion engine on the road to victory. The impact almost a century later needs no elaboration.

For market failure to happen, especially on the scale causing climate change, animal spirits remain a prominent part of the explanation. Ethics and fairness go hand in hand, for example, and Stern explicitly refutes the neoclassical macroeconomic assertion that ethics can be "revealed" through the market mechanism (see Figure 3). Fairness – one of the animal spirits – towards future generations and between rich and poor nations is among Stern's foremost concerns. Fairness was evidently in short supply when electric and gasoline power struggled for supremacy a century ago.

It is suggested in the introduction to this appendix that the current economic crisis may cause a sea change – it may lead to adjustments in the respective roles of business, government, and the society at large. On the other hand, it may not. The climate threat could provide an even more powerful motivation, or it may fail to break through the institutionalized pattern of inertia and vested interests. This uncertainty explains the decision to incorporate economic policy assumptions as a factor in our four scenarios.

## COMPLEXITY AND THE ROLE OF OTHER DISCIPLINES

Adding complexity theory and complexity economics to the current economic paradigm is a natural extension. It offers new perspectives which should help policy-makers respond to the climate reality by analyzing more efficiently the broad range of emerging complexities, from China's "cleantech" initiatives and their implications for global technological and trade developments, to the intricacies of new taxation and other public policy schemes and international negotiations aimed at climate change protection.

Although neither Akerlof and Shiller, nor Stern, move irrevocably beyond the prevailing economic theory, both ascribe a major role to other disciplines. Akerlof and Shiller's invocation of psychology to explain the animal spirits dates back to Keynes's *General Theory*, and their book is a timely reminder for those immersed in neoclassical economics and the financial and economic policies that flow from that philosophy.

Stern's climate-change model runs more deeply into the top-down versus bottom-up dilemma that confronts economics. Top-down economics rules the standard economic policies and general understanding of economic and fiscal matters. But the issue of climate change can only be captured if it is also tackled from the bottom up, and that approach gains precedence.[77] It is associated with the fate of ecosystems and biodiversity in the broadest sense; with the depletion of natural resources that have taken millions of years to build up; and on the human and institutional level with resistance and vested interests defending "business-as-usual", and ultimately with issues of national and international poverty and security, and risks of warfare and aggravated domestic social unrest.

An important contrast with traditional economics, apart from defining the role of technology as a truly dynamic endogenous driver of growth and development, is the recognition that complexity economics produces indeterminate results. Edwin Black's description of the struggle between electric and gasoline-powered cars a century ago exemplifies how the fate of alternative technologies can be sealed by random events (the Edison fire) and power struggles (GM and others versus Edison and Ford).

Complexity theory will continue developing, and the most important impact of this may be further progress of collaborative efforts between the physical and behavioral sciences. If so, this could have a profound impact on the economic theory and policy of the future, which may show up first in relation to climate change. However, the recognition of what is being almost jocularly referred to as animal spirits is also important: its first impact might be through renewed collaboration between economists, psychologists and other social scientists in the search for a more communally sensitive top-down approach.

## LESSONS FOR CLIMATE CHANGE POLICY FROM RECENT EVENTS

This final section reflects events of 2009-10, including the impact of the global economic crisis and resurgent climate change denial which has been instrumental in bringing about a failure to pass comprehensive emissions trading schemes (ETS) in the USA and other countries including Australia. From being touted as the "ultimate" solution, these schemes through labyrinthine negotiating processes in 2009 were perhaps fatally weakened by compromises and exceptions. This has led many people to say that other instruments such as a straightforward carbon tax or differential treatment of individual industries would be more effective if the world is to proceed toward a non-fossil fuel economy.

These events give an additional climate-policy perspective to the role of economics in complex times, which may resonate in future years. The economic crisis was at least partly responsible for the relative failure of the climate change conference in Copenhagen, Denmark, in December 2009 (COP-15). President Obama was forced to change his political priorities from the very beginning of his administration, and conservative forces gained politically in the process. Other countries had similar experiences, again including Australia with a radicalized conservative opposition.

[77] The same applies in principle to health, education, culture, and other social policies which affect the societal fabric and sense of fairness and equity within and among nations.

## THE COPENHAGEN ACCORD

The Copenhagen Accord[78] was drawn up on the last day of the COP-15 conference by only five participating countries (the United States, China, India, Brazil, and South Africa). It is not legally binding and limited in scope, setting no real targets and no path towards a strong succession agreement to the Kyoto Protocol, which runs out in 2012. This puts the onus on the next UNFCCC conference (COP-16) in Cancún, Mexico, in November-December 2010. COP-16 is preceded by meetings in Bonn, Germany, in April and June, involving the developed Annex I countries and the UNFCCC Subsidiary Bodies, respectively.

Notwithstanding its failure to produce a legally binding framework and a forward path, the Copenhagen Accord gave rise to some noteworthy new thoughts or concepts (Heffernan 2010):

- For the first time in an official declaration, it recognizes the need to limit the increase in global temperature to $2^{O}C$ above pre-industrial levels.
- It commits the developed countries to provide a total of $30 billion between 2010 and 2012 to help developing nations adapt to climate change, rising to $100 billion per annum by 2020, to be administered by a green climate fund.
- It includes aspirational targets for greenhouse gas emissions. Over half of the 192 countries participating in COP-15 (107) had responded by March, when the last two major countries to sign up, India and China, announced their intention to participate. This added considerable credibility to the approach, though the targets fall short of absolute commitments. [79]

Olive Heffernan (2010), editor of the *Nature Climate Change Report*, presented the comments of six international experts on "the road from Copenhagen." These views are encapsulated below:

- Mike Hulme of the University of East Anglia, UK, has formed the view that we need to set near-term targets that are pragmatic, technology-based, and achievable based on credible social, technical and economic analysis, "not aspirational targets driven by IPCC science." "I wouldn't mind too much if the climate bill doesn't get through the Senate if it forces other types of thinking."
- Jonathan Lash of the World Resources Institute, Washington, DC, saw a binding legal agreement, delivered in Mexico, as the ultimate goal. There will be key indicators of progress along the way. The first was the January 31 deadline by which countries were asked to submit their intentions to reduce greenhouse gases (reaching 109 responses by March as noted above, and over 120 by the end of June). Other indicators will be the content of China's 12th Five-Year Plan, 2011-15, and the passage of US climate legislation (this has become a problematical prospect in view of the current political situation and the coming mid-term elections in November ).

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[78] Reproduced in full at http://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf.

[79] The count at the end of June 2010 was "more than 120", of which over 75 had set targets, according to Connie Hedegaard, the EU's climate action commissioner and former Danish climate change and energy minister (http://www.euractiv.com/en/climate-environment/hedegaard-tax-what-you-burn-not-what-you-earn-interview-495623).

- David Victor, Stanford University: COP-15 provided no clear milestones or compass for the next round of diplomatic efforts. COP-16 in Mexico probably won't deliver a clear outcome. The Kyoto Protocol expires in 2012, which may send governments scrambling to secure instruments such as the Clean Development Mechanism, already undermined by the inconclusive outcome in Copenhagen. It is essential to find an acceptable path for the countries that really matter, notably the China and the US. The underlying cause of the failure is a basic lack of public interest in addressing the problem. "So far, very few people are willing to pay substantial amounts of money to avoid uncertain and distant global warming, and government policy reflects that reality."

- Hans Joachim Schellnhuber of the Potsdam Institute for Climate Research, Germany, called COP-15 a "landmark event": (1) The global policy-making elite assembled there confirmed that the scientific evidence on global warming is the frame of reference for all climate-protection strategies. (2) "After almost 20 years of lofty announcements and sustainability kitsch, the meeting made it brutally clear how little the respective sovereign states are willing to contribute to the well-being of humankind."

  Many bilateral and multilateral activities will unfold when the various parties recover from the self-afflicted shock. "Bonn will be a crucial test-bed for avenues beyond the Copenhagen quagmire." A convincing international, legally binding and effective climate agreement must be put in place that is considered "tolerable, if not fair, by practically everybody." There is still time to replace the climate-policy-as-usual agony with such a vision. The problem in Copenhagen was primarily the US and China, not the many small countries. "If the two were willing to cooperate on climate protection, then the UN system would also work fine."

- Roger Pielke Jr., of the University of Colorado, Boulder, felt that there is no way the world will coordinate efforts to stabilize greenhouse gas emissions through binding targets and timetables for reducing emissions. "Yet many in the climate debate seem ready to put the Copenhagen experience out of their minds and gear up for doing it all over again in Mexico City. Insane!"

  The way to achieve any climate change goals is not through global temperature targets but through technology, innovation and economics. There must be a direct focus on decarbonization of the global economy through improved energy efficiency, expanding low-carbon energy supply not through treaties but through processes of innovation "implemented over many, many decades in a frustrating and incremental process." [80]

  These goals are largely compatible with policies focused on improving energy security and expanding energy access for the 1.5 billion people without electricity. "It would be interesting to see countries negotiating an upstream carbon tax and a mechanism for its proceeds to support decarbonization, energy security and enhanced access to electricity. Such negotiations would still be very complicated and political."

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[80] Refer Appendix 6 on technology, which is built around W. Brian Arthur's treatise on the nature of technology (Arthur 2009). Arthur describes the innovative process as time-consuming and complex, but essential for continued progress. Pielke evidently agrees.

- Bill McKibben of 350.org noted that 112 nations – almost 60% of UNFCCC signatories – endorsed a 350 ppm target for atmospheric $CO_2$ in Copenhagen. But he said they were the "wrong" 60% made up by poor and vulnerable countries, and China and the US were not among them. "But in some sense, the US and China, having broken the UN process, also bought it. That is, success and failure are increasingly on their shoulders. We in civil society need to figure out how to highlight that." Success or failure is increasingly dependent on these two countries.

All six commentators would agree with Schellnhuber that the science must be the frame of reference for all climate policy formation – a view nearly universally held.[81] From this crucial consensus, three main viewpoints emerged in Copenhagen:

1. There is a growing realization, following the global financial crisis and COP-15, that fewer people are currently willing to invest substantially in climate change mitigation, and that government policy reflects this. This view was expressed most strongly by Victor and Schellnhuber.

2. The United States and China are the catalysts. Agreement between these will determine whether an effective and legally binding agreement covering all countries can be put in place (Lash, Victor, Schellnhuber, McKibben).

   Whatever politically motivated display they exhibited at COP-15, it is noteworthy that both countries were among the five that put the Copenhagen Accord together, practically in the last hours of the conference. President Obama in his closing statement said nations had made a "meaningful and unprecedented breakthrough" but must continue to seek a legally binding agreement.

   Other sources show that contrary to some still popular perceptions, China is making a massive effort to introduce greener technologies associated with huge business opportunities, so market-driven forces may begin to exert stronger positive influences on climate policy. The *China Greentech Report* (Crachilov et al. 2009) provides a thorough analysis of what may happen across a wide range of Chinese sectors.[82] The preface of the report describes it as an open-source, commercial collaboration of leading green technology companies, entrepreneurs, investors, NGOs and policy advisers.

3. Climate policy must refocus on direct approaches to decarbonization through technological change, innovative processes, energy efficiency, and incentives (Hulme, Pielke). The case for an alternative approach to climate change policy will now be discussed. It may also provide a path past the political unwillingness to deal with climate change through general but punitive devices such as emissions trading schemes.

## A "PRICE COLLAR" TO REDUCE RISK

The volatility and uncertainty of the environment within which countries have to make their commitments to reduce greenhouse gas emissions, is a major macroeconomic concern. The

[81] Chapter 1 of Clive Hamilton's pessimistic book on the future of our species (Hamilton 2010) is titled "No escaping the science." All else flows from that. See further Appendix 6.

[82] Summarized in Appendix 6.

magnitude of the problem is amply demonstrated by the global economic crisis. Additional uncertainties include unexpected economic growth, technological breakthroughs, price trends for renewable energy, and political instability. It is very difficult, in this environment, to establish price targets for greenhouse gas emissions that are demonstrably comparable across countries.

The Brookings Institution's policy director of climate and energy economics, Adele Morris, has advocated a "price collar" to ensure comparable efforts by nations based on comparable price signals for carbon (McKibbin, Morris and Wilcoxen 2009). The price collar sets starting floor price and price ceilings, which then rise annually for a ton of carbon dioxide-equivalent emissions at a predetermined rate plus adjustment for inflation, over the course of the agreement. Morris and her colleagues see the price collar as an effective and economically viable way to move international climate negotiations forward, especially for developing countries where the future uncertainties and the cost are greatest. Focusing exclusively on reductions of historical levels of emissions has greatly hampered climate negotiations. Introducing a sensibly defined price collar would provide a way of easing countries into the agreement by reducing the risk and uncertainty, and offering a transparent and verifiable assurance that countries put in a comparable effort.

A price collar has been adopted in the climate legislation being proposed by Senator Kerry and his colleagues, as reported in the next section.

### SHOULD CLIMATE POLICY CHANGE RADICALLY?

An argument in favor of an alternative approach to "getting climate policy back on course" was put forward in a paper under the auspices of the London School of Economics and the University of Oxford (Prins et al. 2009). Co-authors include Mike Hulme and Roger Pielke, whose comments were summarized in the previous section. The paper was published months before COP-15 but reflects the difficulties caused by the economic crisis. Another paper has since been published following COP-15, reported at the end of this section (Prins et al. 2010).

Prins et al (2009) demonstrates that there has been no acceleration in the rate at which the main economies, the European Union, United States, Japan, and China, have "decarbonized" in terms of *carbon intensity* – tons $CO_2$ produced per thousand dollars of GDP adjusted for inflation. Indeed, the data show China "*re*carbonizing" between 2002 and 2006, the last year included.

The paper is based on the so-called Kaya identity which elegantly ascribes changes in $CO_2$ emissions to just one of four factors: population, wealth (GDP per person), energy intensity (energy used per unit of GDP), and carbon intensity ($CO_2$ produced per unit of GDP). Bill Gates (2010) in a public presentation commented on each element of the identity (Emissions = P × S × E × C) in the following terms:

- *P = population* is expected to increase from just under 7 billion in 2010 to just over 9 billion by 2050 (it then starts declining according to the main global scenarios A1 and B1). Some but not much control can be exerted on this element over the next few decades.

- *S = services* (Gates's terminology; the proxy is GDP at constant prices per person) is also largely a given in planning terms, and will continue to increase. The developing world, led by China and India, will insist on benefiting from increasing wealth.
- *E = energy intensity* is falling, not rising, in contrast to P and S. In some economic sectors, energy efficiency may increase by up to 90%. While the potential varies widely from sector to sector, considerable overall improvement is possible according to Gates. Energy efficiency is one of three main categories of technological change described in Appendix 6. The others are new energy technologies and land and coastal management.
- *C = carbon intensity* is the key factor. It will not fall through continued conventional use of coal and natural gas, but through what Gates calls "energy miracles" of which he selects five for further consideration: carbon capture and storage, nuclear energy, wind power, solar photovoltaic power, and solar thermal power. The relative merits of these choices in Gates's view are discussed in the section on nuclear fission in Appendix 6.

The Kaya identity is named after Professor Yoichi Kaya of Keio University, Tokyo, Director-General of Japan's Research Institute of Innovative Technology for the Earth. Prins et al. (2009) credited Kaya with the insight that the four components are the *only* macro-scale policy levers that affect $CO_2$ emissions.[83]

The main message of the paper is (Prins et al. 2009, p 3): "If countries really aspire to cut emissions, we suggest that the motor of an effective mechanism is a direct approach to the decarbonization of the global energy system, rather than an indirect approach via manipulation of the economy. The logic behind this direct approach is explained by the Kaya Identity."[84]

Each of the four factors in the identity is amenable to the action of a particular lever and each lever prescribes a particular approach to policy. "In the case of population, the lever is population management. In the case of wealth, the lever is to reduce the size of the economy. In the case of energy intensity, the lever is to increase energy efficiency. And for carbon intensity, a switch to energy sources that generate fewer emissions is the primary lever." (p 4)

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[83] The Kaya identity was explored by Waggoner and Ausubel (2002), who found it related generally to dematerialization, not just decarbonization, though $CO_2$ reduction was part of the examples given. The authors noted the connection between the Kaya identity and the "IPAT identity" developed in 1972 by Barry Commoner, Paul Ehrlich, and the future science and technology adviser to President Obama, John Holdren (references in Waggoner and Ausubel 2002). IPAT defined the environmental impact (I) of population (P), affluence (A), and technology (T). Of these, only population has retained its original meaning, while impact, affluence (which Gates called S) and technology (E×C in Kaya) have all changed definitions and dimensions. Technology, for instance, has been cast as both villain and hero and has been a mere residual left over – a treatment which goes straight against the concept of technology demonstrated in Appendix 6. Hamilton (2010, p 46) analyzes IPAT, finding it places an almost impossible burden on the role of technology. Looking at energy and carbon intensity individually still indicates a formidable task, but at least these elements can receive separate focus through the Kaya identity.

[84] What seems a portent happened in April 2010 when the investment newsletter, *The Green Chip Review*, finally – almost a year after Prins and his colleagues published their paper – acknowledged the nail in the coffin of cap-and-trade, after having avidly supported it previously. It blamed the change on fraudulent use of existing schemes in Europe and Asia and "highly bureaucratic language and complicated rules." Carbon dioxide emissions should be priced because the atmosphere is not a public good, but a straight carbon tax would benefit the competitive position of clean-energy companies. "Instead of paying for carbon permits, a tax would force utilities and manufacturing businesses to adopt more sustainable practices." (Hodge 2010)

As Gates (2010) shows, population management and reducing the economy are politically unrealistic, which leaves policies to improve energy efficiency and switching to renewable energy. [85] Prins et al. (2009) agree and "for reasons of political feasibility as well as of efficiency" define what they call the Kaya Direct Approach "focusing on energy intensity and carbon intensity and not on population and wealth." (p 10)

The paper concentrates on the prospects for decarbonization as a focus of those factors that articulate with greenhouse gas emissions and economic growth, rather than "an indirect and perhaps non-existent chain of causations." (p 4)

The authors conclude (pp 14-15):

1. The Kaya Direct Approach offers the best way forward for decarbonization, and humanity will perhaps inevitably pursue this approach in view of the political realities of energy and climate policies around the world.
2. This is consistent with incorporating new science into policy-making because it preserves an ability to adjust to new knowledge and policy performance. Climate policy must be robust to uncertainties that can break in any direction. The approach improves efficiency and reduces costs, which reliably translates into greater profitability.
3. The momentum of climate policy was brutally halted by the recession, but this offers a chance of replacing dogmatism with pragmatism – taking a direct approach to decarbonization rather than setting targets bound to be vigorously opposed by voters and elected politicians. The focus should switch to actions that have worked in the past and are politically feasible, away from the current approach which has not worked in the past and has not yet proven to be politically feasible.

Reviewing a batch of new "post-Copenhagen" books for *Nature*, Pielke (2010) finds climate change at a crossroads, and once again asserts his conviction that continuing down the path followed to date will not work.

"Climate science has become deeply politicized and climate politics is in gridlock. Climate change is at risk of becoming an issue of cultural politics, similar to the evolution debate in the United States and elsewhere. If the climate-policy debate is to continue as it has, we should expect more of the same.

An alternative way forward would start by admitting the limitations of science in compelling political agreements, and by admitting that we do not know how to complete the challenge of decarbonizing the global economy. There may be greater prospects for political consensus if scientists acknowledge their humility rather than asserting their authority. Incremental approaches to climate mitigation that can be modified by experience offer a chance that realistic and democratically grounded actions might rise to a challenge that will be with us for decades to come." (p 353)

Prins and some of his co-authors of the 2009 paper including Mike Hulme and Roger Pielke have since taken the message further (Prins et al. 2010, dubbed "The Hartwell Paper"). "The

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[85] There may be marginal efforts to influence P and S, like encouraging the reduction of birth rates in countries lagging behind the general international trend, and even placing subtle restrictions on the growth rates of rich countries, but the total effect of such measures over the coming few decades is unlikely to have major potential.

UNFCCC/Kyoto model of climate policy cannot continue because it crashed in late 2009. .. The crash of 2009 presents an immense opportunity to set climate policy free to fly at last." (p 6) The failure of the Copenhagen conference in December to secure a binding agreement (coupled with the critique of IPCC's authority which emerged in early 2010 over "mistakes") therefore supported the conclusions reached in the 2009 paper of Prins and his co-authors.

Concerned that "the current framing and climate change and climate policy has 'boxed us in'" (p 8), the new paper advocates a radical reframing of the approach, accepting that decarbonization will only be achieved successfully as a benefit contingent upon other goals which are "politically attractive", "politically inclusive", and "relentlessly pragmatic." (p 11)

The paper advocates that the organizing principle of the effort to combat climate change should be "the raising up of human dignity [86] via three overarching objectives: ensuring energy access for all; ensuring that we develop in a manner that does not undermine the essential functioning of the Earth system; ensuring that our societies are adequately equipped to withstand the risks and dangers that come from all the vagaries of climate, whatever their cause may be." (p 5)

Above all, the paper "emphasizes the primacy of accelerating decarbonization of energy supply. This calls for very substantially increased investment in innovation in non-carbon energy sources in order to diversify energy supply technologies. The ultimate goal of doing this is to develop non-carbon energy supplies at unsubsidized costs less than those using fossil fuels. The Hartwell Paper advocates funding this work by low .. dedicated carbon taxes."

The technological Appendix 6 refer to the futility of single solutions to climate change and in effect advocates multiple approaches across the range of renewables, energy efficiency, and the maintenance and preservation of carbon sinks – as well as the pointing to the importance of diffusing new technologies and genuine innovation to a wide range of nations.

## IMPLICATIONS

As Prins et al. (2010) emphasize, the outcome in Copenhagen indicated that the approach taken to date needs to be considerably or even radically modified. A successor agreement to the Kyoto Protocol based solely on the top-down UNFCCC policy process is unlikely to succeed unless it is strongly supported by the domestic policies of the major industrialized and developing economies. The failure of the Obama administration to secure the passage of a cap-and-trade bill through the Senate in 2009 weakened the American influence on the Copenhagen Accord at a time when strong leadership was called for.

Efforts to put a United States climate bill through the Senate were revived in November 2009 when Senators John Kerry (D-MA), Joe Lieberman I-CT), and Lindsey Graham (R-S.C.) got together to explore bipartisan support. In March 2010, Senate majority leader Harry Reid urged Senator Kerry and his colleagues to produce a proposal with all possible speed. An

[86] Currently, all the framings and agendas are mobilized to advance the one core goal of decarbonizing the energy system via the UNFCCC/Kyoto process. (p 9) Prins et al. (2010) that this principle of attacking "sinfulness" hasn't worked; but a positive approach should work better.

eight-page outline was discussed with senators and leading industry associations on March 18, reported to call for greenhouse gas curbs across multiple sectors to achieve a 17% reduction below 2005 levels by 2020 and an 80% reduction by 2050.[87] The trio had scrapped a wide-ranging cap-and-trade system in favor of one covering the 40% of emissions associated with electric utilities which would provide the main revenue for the broader legislation. Subsequently, Senator Graham withdrew his support, leaving the initiative in the hands of Senators Kerry and Lieberman.

The draft dealt in turn with refining, America’s farmers, consumer refunds, clean energy innovation, coal, natural gas, nuclear, and energy independence. The proposal was also reported to introduce a “hard price collar” limiting greenhouse gas emissions to between $10 and $30 per ton, tagged to inflation and with an increase at a fixed rate for future years. This was the exact concept promoted by Adele Morris and her colleagues to reduce uncertainty and risk (McKibbin et al. 2009).

President Obama expressed strong support for a bipartisan effort to establish clean energy incentives that will create jobs and reduce America’s dependence on foreign oil. The best way to drive a transition to a clean-energy economy was to give business the predictability and continuity it needs to make investments.

As this report was nearing its conclusion in July 2010, the outlook for passing a climate bill through the Senate before the mid-term elections in November became highly uncertain, but a fourth attempt was being prepared after three failures in 2009. Senators Kerry and Lieberman were reworking their compromise climate bill, concentrating on power plants and removing provisions to phase in other sectors at a later date. Senate majority leader Harry Reid was working on a climate and energy draft bill that might include the power plant caps from the Kerry-Lieberman bill within a wider alternative energy plan. Reid’s initiative looked the best chance of making headway in the Senate, but would be constricting the chances of contentious legislation getting through.

In early July, President Obama convened a cross-party group of twenty Senators constituting the main players in the climate legislative debate to urge them to pass climate legislation with a price on carbon emissions. Obama did not prescribe any particular approach (*Carbon Positive* 2010).

By signing onto the Copenhagen Accord in December 2009, the United States accepted the goal of cutting 2005 domestic greenhouse gas emissions by 17% by 2020. This appears to be

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[87] On March 31, 2010, President Obama announced a decision to open up oil and gas exploration in three areas: "We're announcing the expansion of offshore oil and gas exploration but in ways that balance the need to harness domestic energy resources and the need to protect America's natural resources. .. This announcement is part of a broader strategy that will move us from an economy that runs on fossil fuels and foreign oil to one that relies more on homegrown fuels and clean energy. And the only way this transition will succeed is if it strengthens our economy in the short term and long term." The plan would allow drilling along the Atlantic coastline, the eastern Gulf of Mexico (125 miles off Florida’s coast), and the north coast of Alaska. It would end a longstanding moratorium on exploration from the northern tip of Delaware to the central coast of Florida, covering 167 million acres of ocean. The Pacific coast would remain closed to oil and gas exploration.

President Obama’s decision was attacked by environmental interests and politicians, including senators from Florida pointing out the risks to the state’s economy and environment. He was reported to be hoping to get support from Republicans for a climate change bill in turn for his concession to the oil and gas exploration industry. The Gulf oil spill disaster in May 2010 may also assist in securing support, as suggested in Scenario B1.

the one area of consensus on US climate action, although the target fell short of international expectations for a new global climate agreement. Eileen Claussen, president of the Pew Center on Global Climate Change said a cap on utility emissions would result in a 12-14% cut by 2020. "It's not 17, but I think it's not terrible," she said.

However, the estimate assumed that the utility cap-and-trade program would be coupled with other pollution-reduction steps, such as requiring more fuel-efficient heavy trucks and improving building efficiency standards – initiatives that could be folded into a large energy and environment bill. According to Pew, the reductions in utility sector emissions alone in the draft law translated roughly into an economy-wide 7% cut in fossil fuel pollution by 2020 (Cowan 2010).

Whatever will be the final outcome in the USA, a universal cap-and-trade scheme is becoming less likely, which may also reduce the probability of such schemes being introduced in other countries. While the cap has been seen by some as the most efficient way of legislating a total limit on emissions, the scheme at least in the perspective of 2010 no longer appears to be politically feasible. Moving away from a universal cap-and-trade system implies that other financial revenue schemes will take up the slack, including carbon-based taxes. To be politically acceptable, it has been suggested such taxes should be revenue-neutral, offset by tax relief including lower payroll and other distorting taxes.

So climate policy seems likely to become based on a more piecemeal approach, with cap-and-trade schemes limited to public utilities and a variety of other schemes being phased in for other industries. This would be generally in line with the idea of tackling greenhouse gas emissions through a range of direct approaches to the two parts of the Kaya identity that can be most effectively influenced: energy efficiency and carbon emissions per unit of GDP.

### THE KEY ISSUES REMAIN LARGE-SCALE

- The primary issue is unchanged: the scientific evidence is clear that tackling climate change is becoming increasingly urgent. Despite what happens at international conferences and what is revealed through domestic polls and government policies, the idea that climate change doesn't exist or is going away is erroneous and damaging.
- Climatologists and other scientists urgently need to sell their message more convincingly to all stakeholders, encouraging a genuine dialogue where the scientists listen as well as lecture. As the previous point makes clear, the urgency of introducing effective climate change policies nationally and internationally has not gone away.
- Science and economics need to work together to understand how to ensure climate control. The scientific evidence was the subject of Appendix 3. The present appendix is an extended argument for updating the state of economic thought on a continuing basis. Science is the catalyst but economics is the lubricant which helps change happen and be accepted. Just as science can get its arguments and findings wrong, the economic lubricant can be more or less efficient. Both need to be as competent and comprehensible as possible at all times.
- The outcome in Copenhagen, influenced by the global economic crisis, has damaged the top-down approach to securing binding overall emissions targets. However, the targets

remain highly relevant. The Copenhagen Accord fortunately recognized that the increase in global temperature must be limited to 2$^{O}$C above pre-industrial levels.

- While Sino-American cooperation may have been a dominant issue in Copenhagen, the thread running through the conference was the need to support developing countries in their climate change policies. The pledge to distribute funds through a green climate fund is a promising beginning, but is it enough and will it be rigorously followed up?
- The dynamics of international climate policy may never be the same again if China's "greentech" initiative takes off as dramatically as anticipated. The impact may be disruptive, or it may prove highly constructive and provide a powerful lever for future international negotiations. There are further questions: will China be unique in this respect, or will there be international ripple effects? Or will there be independent moves in other countries or regions? Where is the next economic miracle likely to be?
- National policy evidenced by current US efforts is not favoring a comprehensive cap-and-trade regime, but it may back a partial one based on the electrical utility sector. The likely approach now is to treat each industry sector in its own context, which is in line with the decarbonization approach directed toward the fourth element of the Kaya identity on how to minimize carbon intensities. This principle seems meritorious.
- Breaking the policy measures up into smaller parts with a flexible set of priorities encourages massive lobbying. It should be possible, however, to put some boundaries on this through clear policy directions and guidelines across the range of technological options – in any case, the lobbying was also massive prior to the financial crisis. Some possible options are being explored, for example through the US Department of Energy's ARPA-E program described in Appendix 6.

## THE ECONOMIC PARADIGM UNDER ALTERNATIVE SCENARIOS

This appendix has drawn on a wide number of sources to help identify how economics and economic policies may develop in future:

1. The renewed recognition of "irrational" behavior patterns under the heading of "animal spirits"
2. The recognition of climate change as the cause of the largest market failure ever
3. The influence of complexity theory and general influences from other social and physical sciences
4. Influences since the onset of the global economic crisis.

The economic paradigm differs between the four scenarios, as shown in Chapter 6 of the main report. Without going into detail, the currently prevailing economic thinking is likely to be most prominent in the global economic growth-oriented A1 scenario, whereas the environmentally attuned B1 gives more space to the economics of climate change and the collaboration between economists and scientists. The paradigm is different again in the regionalized scenarios, A2 and B2, partly because of the projections of continued population growth in these scenarios, though the worlds they depict are poles apart.

## ADDENDUM 1: ANIMAL SPIRITS IN THE *GENERAL THEORY*

Chapter 12 of Keynes' *General Theory* is titled *The state of long-term expectation* (pp 147-164 in the original 1936 version). The chapter reads almost as freshly today as it did when written, and brings the "animal spirits" which he introduced towards the end, into focus. It is all about investment, being part of Book 4 of the *General Theory*, which he called *The inducement to invest*.

The chapter has eight parts, from I to VIII (VII on animal spirits is quoted in full).

I. The previous chapter established that "the scale of investment depends on the relation between the rate of interest and the schedule of the marginal efficiency of capital corresponding to different scales of current investment, whilst the marginal efficiency of capital depends on the relation between the supply price of a capital-asset and its prospective yield." (P 147)

   The state of psychological expectation covers the state of long-term expectation (as distinct from the short-term expectation where a producer estimates what he will get for a product if produced today on his existing plant).

II. The state of long-term expectations on which our expectations are based does not depend solely on the most probable forecast we can make. It also depends on the *confidence* with which we can make this forecast – how we rate the likelihood of our best forecast turning out quite wrong. If we expect large changes but are very uncertain as to what precise form these changes will take, then our confidence will be weak.

   The *state of confidence* is very important to business people but economists have not analyzed it carefully. "In particular, it has not been made clear that its relevance to economic problems comes in through its important influence on the schedule of the marginal efficiency of capital. There are not two separate factors affecting the rate of investment, namely, the schedule of the marginal efficiency of capital and the state of confidence. The state of confidence is relevant because it is one of the major factors determining the former, which is the same thing as the investment demand schedule." (p 149)

   "There is ... not much to be said about the state of confidence *a priori.* Our conclusions must mainly depend upon the actual observation of markets and business psychology. This is the reason why the ensuing digression is on a different level of abstraction from most of this book." (p 149)

   To bring the point home, the discussion of the state of confidence that follows assumes that there are no changes in interest rates.

III. We know little about how to estimate the yield of a railway, copper mine or textile factory 10 years hence, or even five years hence. And with the separation between ownership and management epitomized by the stock exchange "a new factor of great importance has entered in, which sometimes facilitates investment but sometimes adds greatly to the instability of the system." (pp150-151) " ... "Thus certain classes of investment are governed by the average expectation of those who deal on the Stock Exchange as revealed in the price of shares, rather than by the genuine expectations of the professional entrepreneur." (p 151)

IV. In practice, we rely on a *convention*, assuming that the existing state of affairs will continue indefinitely, except when we have reason to expect a change. "We are assuming, in effect, that the existing market valuation, however arrived at, is uniquely *correct* in relation to our existing knowledge of the facts which will influence the yield of the investment, and that it will only change in proportion to changes in that knowledge … ." (p 152)

V. Weak points of the convention:

  a. The element of real knowledge in the valuation of investments by those who own them or contemplate purchasing them has seriously declined as a result of the separation of ownership and management due to the stock market.
  b. "Day-to-day fluctuations in the profits of existing investments, which are obviously of an ephemeral and non-significant character, tend to have an altogether excessive, and even an absurd, influence on the market." (pp 153-154)
  c. "A conventional valuation which is established as the outcome of the mass psychology of a large number of ignorant individuals is liable to change violently as the result of a sudden fluctuation of opinion due to factors which do not make much difference to the prospective yield … ." (p 154)
  d. The attention of expert professionals who have better judgment and knowledge is elsewhere. They are concerned not with making superior long-term forecasts but with forecasting changes in the conventional basis of valuation a short time ahead of the general public. They are concerned with market valuation based on mass psychology, three months or a year ahead.
  e. The other facet of the *state of confidence* is the confidence of the lending institutions towards those who seek to borrow from them, sometimes described as the *state of credit*. Either the state of confidence or the state of credit can cause a collapse but recovery requires the revival of both. "For whilst the weakening of credit is sufficient to bring about a collapse, its strengthening, though a necessary condition of recovery, is not a sufficient condition." (p 158)

VI. *Speculation* is the activity of forecasting the psychology of the market; *enterprise* is the activity of forecasting the yield of assets over their whole life. While speculation does not always predominate over enterprise, the influence of speculation on Wall Street is enormous. "Even outside the field of finance, Americans are apt to be unduly interested in discovering what average opinion believes average opinion to be; and this national weakness finds its nemesis in the stock market" (p 159). As distinct from the British, he buys equity for capital appreciation rather than "for profit". "It is usually agreed that casinos should, in the public interest, be inaccessible and expensive. And perhaps the same is true of Stock Exchanges." (p 159)

VII. The animal spirit chapter is quoted in full (pp 161-163):

"Even apart from the instability due to speculation, there is the instability due to the characteristic of human nature that a large proportion of our positive activities depend on spontaneous optimism rather than on a mathematical expectation, whether moral or hedonistic or economic. Most, probably, of our decisions to do something positive, the full consequences of which will be drawn our over many days to come, can only be taken as a result of animal spirits – of a spontaneous urge to action rather than inaction, and not as a result of a weighted average of quantitative benefits multiplied by quantitative probabilities. Enterprise only pretends to itself to be mainly actuated by the statements in its own prospectus, however candid and sincere. Only a little more than an expedition to the South Pole, it is based on an exact calculation of benefits to come. Thus if the animal spirits are dimmed and the spontaneous optimism falters, leaving us to depend on nothing but a mathematical expectation, enterprise will fade and die; – though fears of loss may have a basis no more reasonable than hopes of profit had before.

It is safe to say that enterprise which depends on hopes stretching into the future benefits the community as a whole. But individual initiative will only be adequate when reasonable calculation is supplemented and supported by animal spirits, so that the thought of ultimate loss which often overtakes pioneers, as experience undoubtedly tells us and them, is put aside as a healthy man puts aside the expectation of death.

This means, unfortunately, not only that slumps and depressions are exaggerated in degree, but that economic prosperity is excessively dependent on a political and social atmosphere which is congenial to the average business man. If the fear of a Labour Government or a New Deal depresses enterprise, this need not be the result either of a reasonable calculation or of a plot with political intent; – it is the mere consequence of upsetting the delicate balance of spontaneous optimism. In estimating the prospects of investment, we must have regard, therefore, to the nerves and hysteria and even the digestions and reactions to the weather of those upon whose spontaneous activity it largely depends.

We should not conclude from this that everything depends on waves of irrational psychology. On the contrary, the state of long-term expectation is often steady, and, even when it is not, the other factors exert their compensating effects. We are merely reminding ourselves that human decisions affecting the future, whether personal or political or economic, cannot depend on strict mathematical expectation, since the basis for making such calculations does not exist; and that it is our innate urge to activity which makes the wheels go round, our rational selves choosing between the alternatives as best we are able, calculating where we can, but often falling back for our motive on whim or sentiment or chance."

VIII. Certain factors mitigate in practice about our ignorance of the future. Due to compound interest combined with the likelihood of obsolescence, it may be legitimate that the prospective yield is dominated by returns occurring in a comparatively near future.

In buildings, the risk can be frequently transferred from the investor to the occupier, or shared between them based on long-term contracts where the occupier buys continuity and security of tenure.

In public utilities, much prospective yield is practically guaranteed by monopoly privilege (rates set to secure a stipulated margin).

A growing class of investments by public enterprises provide social advantages from the investment (whatever the community yield).

In conclusion:

"For my own part I am now somewhat sceptical of the success of a merely monetary policy directed towards influencing the rate of interest. I expect to see the State, which is in a position to calculate the marginal efficiency of capital-goods on long views and on the basis of the general social advantage, taking an even greater responsibility for directly organising investment; since it seems likely that the fluctuations in the market estimation of the marginal efficiency of different types of capital, calculated on the principles I have described above, will be too great to be offset by any practicable changes in the rate of interest." (p 164)

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John Maynard Keynes, *The General Theory of Employment, Interest and Money,* Chapter 12 ("The state of long-term expectation"). Macmillan & Co Ltd, London, 1936.

## ADDENDUM 2: SCHUMPETER ON ECONOMIC DEVELOPMENT

From *Capital, Socialism and Democracy* (1942), pp 82-84:

"The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process. It may seem strange that anyone can fail to see so obvious a fact which moreover was long ago emphasized by Karl Marx. Yet that fragmentary analysis which yields the bulk of our propositions about the functioning of modern capitalism persistently neglects it. Let us restate the point and see how it bears upon our problem.

Capitalism, then, is by nature a form or method of economic change and not only never is but never can be stationary. And this evolutionary character of the capitalist process is not merely due to the fact that economic life goes on in a social and natural environment. … The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates.

The contents of the laborer's budget, say from 1760 to 1940, did not simply grow on unchanging lines but they underwent a process of qualitative change. Similarly, the history of the productive apparatus of a typical farm, from the beginnings of the rationalization of crop rotation, plowing and fattening to the mechanized thing of today – linking up with elevators and railroads – is a history of revolutions. So is the history of the productive apparatus of the iron and steel industry from the charcoal furnace to our own type of furnace, or the history of the apparatus of power production from the overshot water wheel to the modern power plant, or the history of transportation from the mail-coach to the airplane. The opening up of new markets, foreign or domestic, and the organizational development from the craft shop and factory to such concerns as U.S. Steel illustrate the same process of industrial mutation – if I may use that biological term – that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in. This fact bears upon our problem in two ways.

First, since we are dealing with a process whose every element takes considerable time in revealing its true features and ultimate effects; we must judge its performance over time, as it unfolds through decades or centuries. A system – any system, economic or other – that at every given point of time fully utilizes its possibilities to the best advantage may yet in the long run be inferior to a system that does so at no given point of time, because the latter's failure to do so may be a condition for the level or speed of long-run performance.

Second, since we are dealing with an organic process, analysis of what happens in any particular part of it – say, in an individual concern or industry – may indeed clarify details of mechanism but is inconclusive beyond that. Every piece of business strategy acquires its true significance only against the background of that process and within the situation created by it. It must be seen in its role in the perennial gale of creative destruction; it cannot be understood irrespective of it or, in fact, on the hypothesis that there is a perennial lull."

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# APPENDIX 6: TECHNOLOGY AND CLIMATE CHANGE

## OVERVIEW

This appendix was inspired by W. Brian Arthur's book, *The Nature of Technology* (2009a), summarized at the end. A distinction is made between energy technologies, measures to improve energy efficiency, and technologies to improve land and coastal management (Cosier 2008, Nellemann et al. 2009). Without relying entirely on their opinions, two main sources provide a framework for assessing technologies (Jacobson 2009, Goodall 2008).

Other sources assist in classifying descriptions of individual technologies into the three classes. The final section deals with the diffusion of technologies with an emphasis on the least developed countries, reflecting the observation that climate change and the poverty trap are the most urgent pair of issues facing the world (Stern 2009). The section includes descriptions of current trends in biotechnology, technologies exploring alternative ways to industrialized agriculture, and the role of technology in assisting the least developed countries, including Sub-Saharan Africa.[88]

## RISING INTEREST IN INNOVATION IN THE SOCIAL SCIENCES

Innovation and new technology was long a neglected research area. One statistical indicator shows that scholarly research contributions were few and far between before 1960: only about 0.04% of all social science titles in the second half of the 1950s included the word "innovation". By 1991-93 the proportion had grown to about 0.2% and it then surged to 0.4% between 2002 and 2006 (Fagerberg and Verspagen 2009).[89] A worldwide web-based survey in 2004-05 of over one thousand social scientists (60% of whom were economists) showed that the prime source of inspiration across the board was Joseph Schumpeter, who has been dead for sixty years and developed his basic theories a century ago. The authors observe (p 220):

"Working in the early days of social science, he combined insights into economics, sociology and history into a highly original approach to the study of long run economic and social change, focusing in particular on the crucial role played by innovation and the factors influencing it. In so doing he distanced himself from the (then) emerging neoclassical strand of economics .. . Schumpeter's life-long advocacy for seeing innovation as the driving force behind economic and social change seemed almost a lost cause at the time of his death in

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[88] Professor John Villadsen read a previous draft of Appendix 6, and the final version benefits from his many comments, especially in the areas of nuclear power, biofuels, and biotechnology. The subject of technology has been the hardest to keep up-to-date during the extended time taken to complete the Florida Keys project. All we can hope is to capture the essential character of what is going on in the multifarious areas of technological development that have potential influence on the rate of climate change.

[89] This may look low but reflects the wide coverage of the source: the Social Sciences Citation Index of Thomson Reuter's *Web of Science*, which compiles the essential data from 2,474 of the world's leading social science journals across 50 disciplines, as well as 3,500 of the world's leading scientific and technical journals. See http://thomsonreuters.com/products_services/science/science_products/a-z/social_sciences_citation_index. The real significance is that the *relative* number of references has increased tenfold in 50 years, and doubled in about 12, and the actual number has mushroomed even more as the total number of journal references itself.

1950. Instead, the economics literature increasingly came to be dominated by highly mathematized, static, equilibrium exercises of the type that Schumpeter admired but held to carry little promise for improving our knowledge about the sources of long run technological, economic and social change." [90]

The revived interest in innovation and technology among economists and other social scientists is a welcome sign as the threat from climate change escalates. The Swedish Tällberg Foundation exemplifies organizations that advocate new and creative solutions based on humankind's interconnectedness, systemic interdependence and requirements for courageous and honest leadership. Its founder and chairman, Bo Ekman, a former member of the Volvo management team, in anticipation of the COP-15 meeting in Copenhagen in December 2009 joined NASA's James Hansen in drawing attention to the growing scientific consensus that atmospheric $CO_2$ content should be reduced to 350 ppm. Ekman recognizes this task as "herculean" but the 450 ppm target is rapidly becoming regarded as too risky (Ekman 2008, Hansen 2008, Ackerman et al. 2009, Steffen 2009). Ekman refers to the central role of technology by invoking Brian Arthur's work discussed below (Arthur 2009a):

"Brian Arthur, the brilliant Irish economist, observes in his [then] forthcoming book on the theory of technology that technology brings hope but that trust can only be achieved through our conscious relationship with nature. Trust and hope must be fundamental ingredients in our vision of the future and the redesign of the Kyoto agreement."

## TECHNOLOGIES AND TECHNOLOGY POLICY

### MESSAGES FROM THE NATURE OF TECHNOLOGY

With our focus on developing alternative future scenarios, four key messages emerge from Brian Arthur's view of the role of innovation and evolving technologies (summarized at the end of this appendix with an addendum on "Arthur's Three Laws"):

1. Technological change is an *endogenous* evolutionary process: every new technology is a combination of parts from preceding technologies, made possible by the constant capture and harnessing of natural phenomena on which the technology depends. It is also a *continuing self-creating* process feeding upon its own evolution.
2. Science and technology co-exist (co-evolve) in a symbiotic relationship. One cannot function properly without the other. Strong science makes for strong technology, and *vice versa*. They may combine to help develop high-tech industries which benefit from increasing returns helping them to become dominant in their markets.

[90] It may be another sign of the times that the respected London-based journal, *The Economist*, launched a new column on business and management, *Schumpeter*, on September 17, 2009. The journal commented in the inaugural column: "Schumpeter's ability to see business straight would be reason enough to name our new business column after him. But this ability rested on a broader philosophy of capitalism. He argued that innovation is at the heart of economic progress. It gives new businesses a chance to replace old ones, but it also dooms those new businesses to fail unless they can keep on innovating (or find a powerful government patron). In his most famous phrase he likened capitalism to a "perennial gale of creative destruction". For Schumpeter the people who kept this gale blowing were entrepreneurs."

3. Inventions (radically novel technologies) are *always* based on a technological base of existing components and functions. The process from prototype invention to major technology and subsequent development of a new technological "domain" is time-consuming and involves complex adaptive interactions with the general economy. Radically inventive new technologies may therefore take decades to make their full impact. Some existing bodies of technology, however, keep "morphing" into new offshoot technologies and new domains in a shorter time frame. Communications and information technology are prominent examples.
4. Technology is mainly seen in physical terms. However, physical technologies interact with a plethora of other ways of fulfilling particular human purposes, such as distribution systems and government institutions. Such "purposed systems" have much in common with physical technologies. The integrated approach to coastal management of which the Florida Keys National Marine Sanctuary forms part exemplifies a purposed system which can be adapted to changing circumstances just as physical technologies can.

### SOME CONSEQUENCES

Accepting that dynamically evolving industries enjoy increasing returns, there are good economic reasons why particular high-tech markets become dominated by a single player, whether a country, company, or product ("Arthur's First Law"). This provides incentives for governments to nurture such technologies, while discouraging monopolistic practices.

There are equally good reasons for national governments to develop policies that are strongly supportive of scientific research because of the intimate bond between science and technology; those failing to do so risk losing out to competitors elsewhere.

A strong national science policy giving priority to well-designed and adequately funded secondary and tertiary education systems and research institutions also helps ensure that the science remains sensitive to new technologies and new scientific findings, which could lead to the best utilization of the available natural phenomena as well as the uncovering of new ones needed for further technological evolution.[91]

The continuing technological evolution which keeps bootstrapping itself on to new levels according to Brian Arthur (and Schumpeter) is an integral part of the economic system. The better this endogenous process is known, the more effectively it can be influenced by government policy. This is relevant in relation to climate change, which despite the growing scientific evidence of its importance keeps getting sidelined in the political process.

International cooperation is essential, but as events in 2009 proved, domestic politics in the United States, China, Australia and other countries keeps interfering with the effort to reach international agreement. The propaganda against early action on climate change has been deafening. The outcome at the Conference of the Parties in Copenhagen in December 2009

[91] A school curriculum too strongly biased towards science may be counter-productive. There are indications that a rounded education including visual arts, music, and other creative activities may produce even better results than an education promoting science only. This is a complex subject debated among educationalists the world over, and we can do no more than flag it here. In the United States, the National Assembly of State Arts Agencies provides critical evidence linking study of the arts with general student achievement and success (Ruppert 2006).

(COP 15) was negatively affected by an abundance of political factors at a time when all the scientific evidence points towards a need for greater urgency, as outlined in Appendix 3. The key political factor was the great recession that hit the world in 2008. As discussed in Appendix 3, the positive effect may be giving incentives a stronger role in a direct approach to the decarbonization of the global energy system, rather than an indirect approach via manipulation of the economy (Prins et al. 2009, p 3).

### FORMATION AND PROGRESS OF ARPA-E

The political waves that were raised in 2009 and their impact on the Copenhagen meeting are fortunately not the only activity that will affect the future. Negotiations on climate change are a continuing process that provides the glue between the annual COP meetings.

Also during 2009 the United States Department of Energy's new agency, the Advanced Research Projects Agency – Energy (ARPA-E), came into being. It is useful to comment on its ambitious aims here, because it helps put the whole climate change-related technology issue into perspective as the story develops below. In its first funding round, ARPA-E allocated a total of $151 million to 37 "transformational R&D" projects (see box). It made its first funding opportunity announcement on April 27 and was flooded with an unexpectedly high number of "concept papers" (3,500) by July. About 300 of these applicants were asked to provide full proposals by the end of August, and the funding was announced on October 26.

**Projects funded by ARPA-E, October 2009**

| Project category | Number* |
|---|---|
| Energy storage | 6.5 |
| Biomass | 4.5 |
| Carbon capture | 5 |
| Renewable power | 4 |
| Direct solar fuels | 5 |
| Building efficiency | 3 |
| Waste heat capture | 2 |
| Vehicle technologies | 5 |
| Water | 1 |
| Conventional energy | 1 |
| * Split categories counted half. | 37 |

Funding of individual projects ranged to below $1 million and averaged just over $4 million. Two projects attracted funding of about $9 million: drilling equipment for geothermal energy and bio-butanol from macroalgae. Although bio-butanol may be more efficiently produced by fermentation in large-scale projects, it was noted that "seaweed is a potentially sustainable *and scalable* [our emphasis] new source of biomass that doesn't require arable land or potable water." Exploring different technologies helps cover a wide range of possibilities both within a nation and between countries at different stages of development.

In another initiative, ARPA-E in August sent out a request for information, or RFI, for public response by September 25.[92] The object was to seek public and stakeholder input into (1) programmatic areas well suited for support by ARPA-E and (2) specific scientific and technological opportunities to overcome the technological roadblocks to developing viable

[92] The RFI letter is shown in full at http://arpa-e.energy.gov/public/rfi.pdf.

transformational technologies relevant to ARPA-E's mission. This would assist the agency in developing potential programs and funding opportunities.

Throughout the letter, it stresses that the responses should emphasize "disruptive new, extremely low-cost approaches to manufacturing high quality products," aimed at "translating cutting-edge scientific discoveries into transformational new energy technologies (i.e. identification of exciting new scientific phenomena and their application to disruptive new energy technologies)."

The letter listed the following program areas of interest:

- Electrification of transport
- Advanced renewable transportation fuels
- Advanced vehicle technologies
- Low cost, scalable, dispatchable centralized renewable power
- Future grid (advanced "smart grid" technologies)
- Distributed energy technologies
- Efficient end use of energy
- Low carbon fossil energy technologies
- Energy materials of the future
- Industrial efficiency.

Other countries are taking other initiatives, and priorities will differ, but the power and ambition of the DOE agency's approach, and the funding amount, certainly shows a high degree of commitment to retain the initiative and develop new technologies as fast as possible, given the inevitable time constraints that Brian Arthur outlines.

### CHINA'S CLEANTECH INITIATIVE

Appendix 5 touched upon the massive efforts that China is exerting to develop new "cleantech" technologies. The central document is the 280-page *China Cleantech Report 2009* (Crachilov et al. 2009), which assembles a comprehensive picture of the various aspects of the technologies that are being pursued. The document is commercial, backed by over 80 leading international corporations and other organizations. The United States Commercial Service (Department of Commerce) is featured as the official market research partner.

The initiative responds to the fact that China's economic development has come at great environmental cost in terms of greenhouse gas emissions, strained water resources, land degradation including desertification and enormous landfill contamination – all caused by a development exceeding anything that has previously taken place in human history in such a short time. It is a process that may see China emerge as the world's largest economy during the next 20-40 years.

To achieve this, China's economic development must become environmentally sustainable out of necessity. China's requirements for greentech solutions are tremendous, and government policies back cleantech market development. China has laid the foundation for cleantech market growth, with the first signs of a green transformation already appearing.

The technologies are discussed in considerable detail in the report, under the following headings supplemented by some of the possible technologies listed in the report:

- Cleaner conventional energy (cleaner coal through carbon capture and storage, cleaner oil, cleaner gas, nuclear energy)
- Renewable energy utilizing the country's extensive solar and wind resources (solar photovoltaic and concentrated solar power, wind power, bioenergy)
- Electric power infrastructure (overcoming shortages, grid connectivity for renewable sources, minimizing energy losses)
- Cleaner transportation (roads, cleaner automotive fuels, hybrid cars; increasing railroad densities; airports and air transport; waterway transport)
- Green building (overcoming negative environmental impacts; introducing green building technology still rare in China; huge potential seen)
- Cleaner industry (energy efficiency, air and water pollution, solid waste)
- Clean water (water extraction, treatment, distribution, and use; wastewater treatment).

It was suggested in Appendix 5 that China's enormous need to become environmentally sustainable may help provide the commercial mechanism needed to secure international agreement on climate change, which stalled at the UNFCCC conference in Copenhagen in December 2009. A number of observers made the point that a successful conclusion of a long-term binding agreement depended on cooperation between the United States and China, with a direct emphasis on decarbonization to prevent the negotiations from bogging down on overall emissions targets. The list above is a living example of how to use a great variety of avenues towards decarbonization.

## CLASSIFICATION CRITERIA IN TECHNOLOGY REVIEWS

Like other topics to be approached in a world threatened by accelerating climate change, the subject matter has mushroomed compared with 2005, when the Florida Keys project was first planned. New literature is added to the knowledge base daily. It is a challenge in these circumstances to achieve the right focus on a complex situation, in a project originally conceived for a simpler world.

As outlined in the next main section, a number of sources have been useful in providing the beginning of a framework, notably a review article on solutions to global warming, air pollution, and energy security (Jacobson 2009), and *Ten Technologies to Save the Planet* (Goodall 2008). They are supplemented by lists of preferred technologies in other sources, and descriptions of individual technologies. The main challenge was to put all the information into a manageable framework.

Two criteria help here. First, technologies that are potential "solutions to climate change" can be classified into three groups (Cosier 2008):

1. Energy technology (say, roughly 50% of the solution according to Cosier)

2. Energy efficiency (25%)
3. Landscape (or land) management (25%).

Cosier regards the third component as the heart of driving a 21st century economic revolution. He calls it "the economics of nature, because it is a giant step towards putting an economic value on the services that nature provides us. Reducing the destruction of these stores of carbon, by reducing land clearing, and by increasing carbon stocks through revegetation and improving soil carbon, makes landscape management a fundamental part of managing the $CO_2$ balance in the atmosphere. "

Such land management technologies have been labeled "green carbon" as distinct from "blue carbon" that covers the role of coastal areas – notably mangroves, salt marshes, and seagrass beds – in transferring $CO_2$ to the ocean on a semi-permanent basis (Nellemann et al. 2009).

Notwithstanding Cosier's statement, a major hurdle for these technologies is the difficulty of putting economic values on particular ecosystems *and* how they link up. As noted in Appendix 4, national accounting for environmental values is falling seriously short of providing true and acceptable estimates. Despite some recent progress, this work still concentrates on local ecosystems and specific natural resources. It excludes the general impact of climate change, and how ecosystems connect. An attempt to value the Great Barrier Reef ecosystem (Oxford Economics 2009) is unconvincing at best as discussed in the main report, Section 6.5.

Finally, our focus is not only on technologies that reduce the threat of climate change but also on those that assist the least developed countries. Both are devices for "saving the world", but the second group act as "enabling technologies" aimed at reducing poverty as well as greenhouse gas emissions.

When poverty is recognized as the twin of climate change, which makes much sense in the context of scenario planning, "enabling technologies" show up strongly (including "purposed systems" as defined by Brian Arthur). They include microcredit, specially created for the developing world, and cell phones, which were not but have proven extraordinarily successful there. Enabling technologies and purposed systems assist alternative smaller-scale solar, biofuel and other technologies appropriate for developed economies in achieving success. The concluding main section of the appendix discusses this further.

## CLASSIFICATION OF TECHNOLOGIES: MAIN SOURCES

The two main sources, as already mentioned, are Jacobson (2009) and Goodall (2008). They are treated under separate headings, followed by other references including the "wedge" analysis by Pacala and Socolow (2004, also in Socolow et al. 2004), which demonstrates that there is no single technological solution to climate change – no "silver bullet".

### SOLUTIONS TO GLOBAL WARMING, AIR POLLUTION AND ENERGY SECURITY

Mark Jacobson (2009) considers the following electric power sources: solar photovoltaics (PV), concentrated solar power (CSP), wind turbines, geothermal power plants, hydroelectric power plants, wave devices, tidal turbines, nuclear power plants, and coal power plants fitted with carbon capture and storage (CCS) technology. He also considers two liquid fuel options: corn-E85 and cellulosic-E85 (85% ethanol, 15% gasoline). He then examines their ability to address the problems mentioned by powering new-technology vehicles, including battery-electric vehicles, hydrogen fuel cell vehicles, and E85-powered flex-fuel vehicles. [93]

The criteria used in Jacobson's assessment are wide-ranging, the most important being $CO_2$-equivalent emissions and human mortality from air pollution, followed by land use and water demand. Other criteria included effects on wildlife, thermal, chemical and radioactive pollution, disruption to energy supply, and operational reliability.[94]

From an analysis in which he develops a score based on his assessment criteria, Jacobson finds that combinations of energy source and vehicle type fall into four tiers:

1. The most efficient combination is battery-electric vehicles (BEV) based on wind power. The overall number two is hydrogen fuel cell vehicles (HFCV), despite the vehicle type being less efficient than BEVs and not otherwise demonstrated as a top option.
2. All combinations in Tier 2 are with BEVs. The top power source is concentrated solar power (CSP) followed by geothermal, photovoltaic, tidal, and wave in that order. Note that all the top options are renewables: wind, water, solar (WWS).
3. Tier 3 is in the "less desirable" range, again comprising power sources for BEVs: hydro, nuclear, and coal-CCS. They have nearly equal overall scores according to the criteria set up, but hydroelectric power squeezes into the "recommended" range as being clean on climate and health, and being "an excellent load balancer". The other two power sources are not recommended.
4. Neither are the ethanol options. They rated lowest overall and in respect to climate, air pollution, land use, wildlife damage, and chemical waste. Cellulosic-E85 ranked lower than corn-E85 overall, primarily due to its potentially larger land footprint based on new data and its higher upstream air pollution emissions compared with corn-E85.

In short, the criteria cover the costs of *externalities* not only of greenhouse gases but also other sources of pollution, damages to the environment, and damages to human health. But renewable costs are rapidly becoming competitive with coal, with wind expected to be the least costly of all sources (Jacobson and Delucchi 2009). Solar energy, still fairly costly, is expected to be competitive by 2020 (Fthenakis et al. 2009). Generally, the field is likely to change considerably, as already seen in relation to new fermentation technology.

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[93] These options are among the most commonly discussed. Other fuel options include algae, butanol, biodiesel, sugar-cane ethanol and hydrogen combustion, electricity options such as biomass, vehicle options such as hybrid vehicles, heating options such as solar hot water heaters, and geoengineering (Jacobson 2009). Some of these options are currently gaining prominence, notably fermentation technologies such as biodiesel.

[94] He also examined the loss of opportunity costs incurred by going down a particular technological path rather than another – finding that the promotion of ethanol, nuclear or carbon capture and storage is backing the wrong technologies at a cost of lost opportunity. This conclusion is controversial and subject to challenge, depending on the geographical setting. Ethanol production in Brazil, for instance, has proven highly successful over 30-40 years despite the alternative use of sugar cane as a food source. More recently, new developments in fermentation technology are enabling the cane and other biomass to be more efficiently and fully utilized, and to combine production of ethanol and sugar (Villadsen 2007, Attfield 2009).

In the interim, however, renewable power will be generally more costly than fossil power. Some combination of subsidies and carbon taxes are therefore required – justified by the hitherto largely uncovered cost of externalities. Jacobson and Delucchi (2009) suggest that a feed-in-tariff (FIT) program to cover the difference between generation cost and wholesale electricity prices is especially effective in scaling up new technologies. “Combining FITs with a so-called declining clock auction, in which the right to sell power to the grid goes to the lowest bidders, provides continuing incentive for WWS developers to lower costs. As that happens, FITs can be phased out.” (p 45)

As of 2009, feed-in tariff policies have been enacted in 63 jurisdictions around the world, including Australia, Austria, Belgium, Brazil, Canada, China, Cyprus, the Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Iran, Ireland, Israel, Italy, Korea, Lithuania, Luxembourg, the Netherlands, Portugal, Singapore, South Africa, Spain, Sweden, Switzerland, and a dozen states in the United States. It was gaining momentum in China, India and Mongolia. The policies applied mainly to domestic photovoltaic solar systems.[95]

Jacobson and Delucchi (2009) present a plan for the world to switch to renewable technologies by 2030, and give the following estimates of needed capacity (assuming financial and technical success of individual technological developments):

- *Water*: 1.1 terawatts (9% of supply), mainly geothermal plants and hydroelectric plants, plus small tidal turbines.
- *Wind*: 5.8 TW (51% of supply). predominantly wind turbines with a small contribution from wave converters.
- *Solar*: 4.6 TW (40% of supply). 1.7 billion rooftop photovoltaic systems, plus about 90,000 concentrated solar power plants and photovoltaic plants @ 300 MW.[96]

These estimates were based on Jacobson (2009), whose later sections deal with available resources for each technology, their effect on climate-relevant emissions ($CO_2e$), land and ocean use, and other variables included in the analysis.

The plan includes only technologies that work or are considered close to working today on a large scale, rather than those that may exist 20 or 30 years from now. The same applies to the technologies analyzed in Jacobson’s (2009) review, which formed the base. This is significant in view of Arthur’s (2009) finding that the introduction of new technologies may take decades. The notes following below include information, wherever possible, on the first appearance of particular technologies in a form relevant in a modern context .

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[95] Wikipedia, “Feed-in tariff”. Accessed March 8, 2010.

[96] Actual clean energy schemes are becoming influential, as shown by the following representative examples. Launched in 2008 by Al Gore, *Repower America* (http://www.repoweramerica.org/us/about/) was introduced as a bold plan to "repower" the United States with 100% clean electricity and revitalize the national energy infrastructure. In July 2009, Gore launched *Safe Climate Australia*, which has similar objectives. Its purpose is “to identify and catalyze action on the societal transformations and solutions needed to achieve a safe climate for Australia, and for the planet, at emergency speed. The structural change achieved in the next ten years is crucial.” http://www.safeclimateaustralia.org/.

## "Ten technologies to save the planet"

While Mark Jacobson's technology analysis concentrates on energy technologies rather than efficiency or land management, Goodall's ten technologies (2008) come from all three categories:

- Energy technologies include wind, solar, the oceans, motor fuels from cellulose, and carbon capture. A sixth technology concentrates on the need to produce the greenest possible cars, where he sees the solution to be battery-only electric cars. Hydrogen as a fuel is an undeveloped technology with no infrastructure where an enormous investment would be needed. Meanwhile, smaller more efficient conventional engines and hybrids still emit $CO_2$ while filling a void. Goodall considered low-carbon fuels from agricultural products (biofuels) as less desirable because they come from sugar cane, wheat or corn. As noted previously, developments in fermentation technology may be changing this perception as the utilization of the biomass improves.
- A seventh technology is a hybrid combining fuel cells (an energy technology) and district heating (an energy efficiency measure that is actually quite old technology). The eighth, "super-efficient homes," is all about energy efficiency.
- The two final technologies are in the realm of the third class that Cosier (2008) called landscape management: sequestering carbon as biochar, and soils and forests (improving the planet's carbon sinks).

Goodall asks (p 254): "If we make substantial progress in each of the ten opportunities described in this book, will we be able to reduce fossil fuel use in advanced economies fast enough? And can we counterbalance the emissions of methane and other greenhouse gases by improving carbon storage in soils and plant matter?" The short answer is yes, but it is a big challenge.

He notes first that the energy footprint of the average person in Britain ("a fairly typical advanced economy") is about 50,000 KWh per person per year, or a continuous energy use of 5,100 watts per person. The bulk of this comes from burning of fossil fuels (some from nuclear energy and a still tiny amount from renewables).

Electricity accounts for about 1,900 watts per person, but this is expected to increase to 2,750 watts due to electric cars (300 watts), replacing gas and oil in manufacturing (300 watts), and increased distance heating (250 watts). Goodall expects this to be replaceable by 2025 with wind power (25%), solar power, mostly concentrated solar power (CSP) in Africa (25%), tidal and wave technology (15%), fuel cells and biomass combined heat and power (10%), and carbon capture and/or nuclear (25%).

"Clearly this is a substantial challenge, but it is far from impossible." (p 257) Offshore wind turbines would fill an area of 100 by 160 km, a small percentage of Britain's continental shelf, and 25% of electricity demand is already met by wind in some European countries. The primary obstacle for solar power generated in deserts is the need for a sustained program of construction of long-distance DC transmission lines, while the growth of electricity supply from tides and waves depends on "continued entrepreneurial activity among the plethora of small firms constructing innovative devices." (p 258) The target for fuel cells also depends on technical progress, particularly towards reducing the cost of cells designed to produce electricity for large commercial buildings. Using biomass for combined heat and power depends on the ready availability of woody materials for fuel, rather than technological advances. (p 258)

This leaves 25% of the total need for power to be met either through coal-CCS (if still using fossil fuels), nuclear technology, or both. CCS technology is a long way from commercial availability. "Indeed, it may be 2020 before we understand how to capture $CO_2$ with reasonable efficiency. But then it should be possible to add carbon capture equipment to most existing coal-fired power stations." (p 258)

Measures to reduce gas demand (currently 1,400 watts per person) would come from space insulation (300 watts), fuel cells (300 watts), replacement by electricity in manufacturing (250 watts), conversion to electric heating (200 watts), and biomass heating (100 watts) – leaving remaining gas demand at 250 watts. Oil demand (currently 1,650 watts per person) would be reduced by electric cars and vans (600 watts), cellulosic and other renewable fuels (200 watts), fuel cells and biomass heating (100 watts), and replacement by electricity in manufacturing (100 watts) – leaving remaining oil demand at 650 watts.

Finally, coal used for other than electricity generation in Britain is about 150 watts per person, mainly for heavy industrial purposes such as in blast furnaces to make iron where it is unlikely to be replaced. The use in other countries varies substantially from this estimate.

Based on Britain, the total need for energy from carbon sources could therefore fall to about one-fifth in a typical advanced economy. "This figure conveniently matches most scientific assessments of the emissions reductions required in rich societies."[97] (p 262) However, there are other greenhouse gases, especially methane and nitrous oxide, and Goodall reckons that all $CO_2$ emissions from fossil fuels should be eliminated to be on the safe side. He relies on soil improvement and biochar for this, as "we can reasonably aim to increase the carbon stored in soils by at least 1 per cent of the weight of the soils themselves." (p 262) The offset of the 1,050 remaining watts per person would be an area as small as 10 by 10 m per annum until the economy is completely decarbonized.

One major problem remains (p 263): "Sequestering carbon in the soil requires us to add plant matter, whether in the form of biochar, longer roots or greater amounts of humus. We also need to use wood and straw for making cellulosic ethanol for fuel cells and car engines and for providing the fuel for biomass heating plants. If guesses in this chapter are approximately correct, we may need 800 continuous watts of our total per capita energy need to come from plants and trees. This is about the same amount of energy we might get from wind or solar power in 2025."

The demand on land to achieve this is very large – say 15% of the area of France if that country chose to use its own land to grow the woody matter it needed. It might make more sense, says Goodall, to grow the wood or straw in developing countries, which would also have the benefit of increasing incomes there, and provide an incentive to reforest large

[97] It is not clear from this whether allowance has been made for population growth. All the estimates, of course, are informed guesses. The stated ambition is to reduce energy demand by 80% by 2025 (whether per capita or totally). Targeted 80% reductions in emissions are usually by 2050.

areas. “But it will still require a significant percentage of the world’s usable land area to be given over to renewable forests for making the raw material for cellulosic ethanol.” (p 264)

Goodall explains the following omissions from the “list of 10”:

- Nuclear power, apart from its safety and storage problems and its long construction lead times, has the worst record of increasing costs of any major technology. In contrast to the cost reductions that can realistically be expected from the major renewable energy technologies, costs per KWh expressed in constant prices have increased strongly over thirty years. (p 268)
- Only one energy efficiency technology gets into the list – better insulated homes. The explanation is simply that house insulation is the single most energy efficiency improvement the world can make, both in cold and warm countries. Any other domestic efficiency measures are dwarfed in comparison. This is not to say, of course, that the appliance and other industries should not continue to improve energy efficiencies. But more could be gained by improving the internal combustion engine and reversing the wasteful use of electricity in offices. Office workers use much more electricity in a 40-hour working week than at home, due to wasteful use of computers, poor building design, and general electricity use. (p 272)
- The last technology missing the list of ten is geoengineering. It is regarded at most as a fallback position – in case reductions in emissions fail to develop or temperature increases begin to induce dangerous instability to the climate. (p 272) It is a contingency planning device which recognizes the environmental risks involved. Goodall mentions three possible geoengineering options (pp 272-276) which are best taken up in the section on individual technologies.

## STABILIZATION WEDGES

In 2004, two Princeton scientists introduced the concept of “stabilization wedges” as a proposed means of solving the climate problem with current technologies (Pacala and Socolow 2004, Socolow et al. 2004). This probably did more than anything to bring home the message that while humanity already possesses the scientific, technical and industrial know-how, there is no single solution (no “silver bullet”) to fix it all. While the best “wedges” may have changed in a

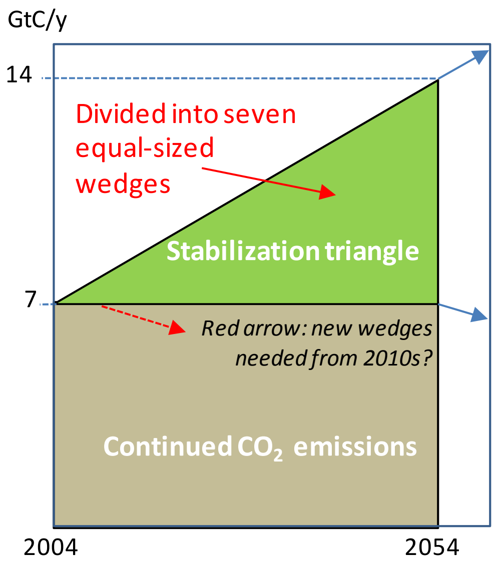


*Figure 1 shows the basic Socolow/Pacala model. The stabilization triangle limits $CO_2$ emissions to present levels. Each of seven technology “wedges” increases linearly until in 50 years it accounts for 1 GtC annually of reduced emissions. The seven-wedge assumption is based on a stabilization level of 500 ppm $CO_2$ and emissions growing by 1.5%/year.*

*The red arrow is a new addition, showing the path of new “below-the-line” wedges as the climate change issue gains urgency.*

rapidly changing technological environment, the wedge concept itself continues to make sense.

Socolow and Pacala adopted a half-century perspective to demonstrate how to deal with climate change relative to a “business-as-usual” scenario, in which they assumed that carbon emissions would continue to increase by 1.5% annually, which was the average for the previous 30 years. This would double annual emissions in 50 years.

The proposed solution was to accept the level of current $CO_2$ emissions (7 gigatons of carbon annually) and to cut future growth by introducing seven technologies as “wedges” which would each be capable eventually of reducing carbon emissions by one gigaton per year. The frame of reference appears to be a stabilization target of 500 ppm, which according to climate models at the time would be compatible with a global average temperature increase of around $3^{O}$C.

The authors said themselves that if emissions were to increase by 2% per annum, about 10 “wedges” would be needed, and if the annual increase was 3%, the number of “wedges” would increase to about 18. Today, five years or more after the research, the assumptions need to be updated, as all evidence has needed updating since the middle of the decade. One paper has updated the basic diagram above, setting the level of continuous annual emissions not at 7 GtC from 2004-2054, but at 11 GtC from 2020-2070, saying this would mean that $CO_2$ levels would reach 1,000 ppm by the end of the century with a best estimate global warming average of +5.5$^{O}$C (Romm 2008). The author justifies this as follows:

“Carbon emissions from the global consumption of fossil fuels are currently above 8 GtC per year and rising faster than the most pessimistic economic model considered by the IPCC. Yet even if the high price of energy from fossil fuels and power plants combines with regional climate initiatives to slow the current rate of growth somewhat, we will probably hit 11 gigatons of carbon emissions per year by 2020.” (Romm 2008, p 85)

To be compatible with the perceived need to remain below a +2$^{O}$C target, which is seen increasingly as necessitating a $CO_2$ target of 350 ppm or less, the comparison with “business-as-usual” would mean that emissions could not be allowed to remain at current levels for 50 years. IPCC’s Fourth Assessment Report and numerous more recent analyses show that emissions, currently growing at over 2% per annum, need to peak and then decline from the mid-2010s to secure these targets. This means finding additional “wedges” to extend the stabilization triangle into what is shown as “continued fossil fuel emissions.” So the downward-pointing arrow beyond 2054 should now start four decades previously. The red arrow on Figure 1 pointing downwards from about 2014 suggests this is a new and very serious challenge indeed, superimposed on the already defined stabilization triangle.

This calls for a dramatic increase in every nation’s sense of urgency, but it doesn’t invalidate the wedge concept. A multiple-technology solution to the problem is still needed, the difference being that more wedges will be needed. Pacala and Socolow suggested 15 wedges, nine of which were energy technologies, four aimed at improved energy efficiency, and two at land management. Each option would indicate the effort needed in 2054 for the wedge in question. Their options and associated key issues are listed and numbered as in the original paper; some statements of course are debatable and possibly outdated six years after the original paper was published.

***Energy efficiency***

1. Efficient vehicles: Increase fuel economy for 2 billion cars from 30 to 60 mpg. Issues: Car size, power.
2. Reduced use of vehicles: Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5000 miles per year. Issues: Urban design, mass transit, telecommuting.
3. Efficient buildings: Cut carbon emissions by one-fourth in buildings and appliances projected for 2054. Issue: Weak incentives.
4. Efficient baseload coal plants: Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today). Issue: Advanced high-temperature materials.

***Energy technologies***

5. Gas baseload power for coal baseload power: Replace 1,400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power). Issue: Competing demands for natural gas.
6. Capture $CO_2$ at baseload power plant: Introduce CCS at 800 GW coal or 1,600 GW natural gas (compared with 1,060 GW coal in 1999). Comment: Technology already in use for $H_2$ production.
7. Capture $CO_2$ at $H_2$ plant: Introduce CCS at plants producing 250 Mt $H_2$/year from coal or 500 Mt$H_2$/year from natural gas (compared with 40 Mt$H_2$/year today from all sources). Issues: $H_2$ safety, infrastructure.[98]
8. Capture $CO_2$ at coal-to-synthetic fuels plant: Introduce CCS at synfuel plants producing 30 million barrels a day from coal if half of feedstock carbon is available for capture (200 times the South African company Sasol, which produces most of that country's diesel fuel). Issue: Increased $CO_2$ emissions, if synfuels are produced without CCS.[99]

   Geological storage (items 6 to 8): Create 3,500 Sleipners.[100] Issues: Durable storage, magnitude and cost of program.

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[98] Pacala and Sokolow (2004) was part of a special section of *Science*: 'Toward a hydrogen economy', which may explain the inclusion of this suggested wedge. Turner (2004) in a subsequent paper in the same issue wrote (p 972): "Hydrogen can be generated from water, biomass, natural gas, or (after gasification) coal. Today, hydrogen is mainly produced from natural gas via steam methane reforming, and although this process can sustain an initial foray into the hydrogen economy, it represents only a modest reduction in vehicle emissions as compared to emissions from current hybrid vehicles, and ultimately only exchanges oil imports for natural gas imports. It is clearly not sustainable."

[99] Synthetic fuels are produced from the Fischer-Tropsch process, developed in coal-rich but oil-poor Germany, to secure sufficient transport fuel during World War Two. Feedstocks are coal (via a gasification process) or natural gas. In 2009, chemists working for the U.S. Navy investigated the use of the process for generating fuels using hydrogen by electrolysis of seawater. This may lead in time to a kerosene-based jet fuel.

[100] Norwegian gas field Sleipner, 250 km west of Stavanger in the North Sea, is the oldest plant that stores $CO_2$ on an industrial scale. Creating 3,500 similar plants seems ambitious, requiring a huge sustained program.

9. Nuclear power for coal power: Add 700 GW (twice the current capacity). Issues noted by Pacala and Sokolow: Nuclear proliferation, terrorism, nuclear waste disposal.

10. Wind power for coal power: Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 300,000 $km^2$, on land or offshore. Comment: Multiple uses of land because windmills are widely spaced.[101]

11. PV power for coal power : Add 2,000 GW-peak PV (700 times the current capacity) on 2 x $10^6$ ha. Issue: PV production cost

12. Wind $H_2$ in fuel-cell car for gasoline in hybrid car: Add 4 million 1-MW-peak windmills (100 times the current capacity). Issues: $H_2$ safety, infrastructure.

13. Biomass fuel for fossil fuel: Add 100 times the current Brazil or U.S. ethanol production, with the use of 2.5 million $km^2$ (one-sixth of world cropland). Issues: Biodiversity, competing land use.

***Land management (forests and agricultural soils)***

14. Reduced deforestation, plus reforestation, afforestation, and new plantations: Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 million ha of new tree plantations (twice the current rate). Issues and comments: Land demands of agriculture, benefits to biodiversity from reduced deforestation.

15. Conservation tillage: Apply to all cropland (10 times the current usage). Issues: Reversibility, verification.

***Comments on original list of wedges***

In his critique of the original paper, four years after its publication, Romm (2008) suggested the following wedges to keep $CO_2$ emissions flat between 2020 and 2070 (eleven, totaling the replacement of 11 gigatons of carbon):

- Efficient buildings: savings totaling 5 million GWh
- Efficient industry: savings totaling 5 million GWh, including co-generation and heat recovery
- Vehicle efficiency: all cars 60 miles per US gallon (>25 km/liter)
- Coal: 800 GW-sized plants with all the carbon captured and permanently sequestered
- Nuclear: 700 new GW-sized plants (plus replacement plants)
- Concentrated solar thermal electric: 1,600 GW peak power
- Solar photovoltaics: 3,000 GW peak power
- Wind power: 1 million large wind turbines (2 MW peak power)
- Wind for vehicles: 2,000 GW wind, with most cars plug-in hybrid electric vehicles or pure electric vehicles

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[101] The required area is approximately the same as Arizona, the sixth-largest state (295,000 $km^2$)

- Cellulosic biofuels: using up to one-sixth of the world's cropland
- Forestry: end all tropical deforestation.

Lynas (2008) discusses the Pacala and Socolow concept in some detail towards the end of *Six Degrees.* He reminds us that we need seven wedges just to stabilize global emissions at their current levels, and also highlights the sheer scale needed to make an impact, in particular for renewables relative to current levels of production (p 295). His final reminder is that we need to limit the global average temperature increase to $2^{O}$C, which will necessitate more wedges (in line with the "red-arrow addition" on Figure 1).

The most controversial technology options according to Lynas (2008) are:

- Nuclear power, despite being a low carbon source with a proven track record in electricity generation. While the technology appears to be increasingly risk-free, it keeps raising the dangers of nuclear weapons proliferation and accidents, and the waste problem is unresolved. It may remain a wedge despite Lynas's assessment, as nuclear technology seems to be moving fast – further discussed later.
- Biofuels, especially from crops. Much of the biodiesel used in Europe comes from palm oil plantations in Indonesia and Malaysia, which have replaced large areas of rainforest. (pp296-297) The ethanol wedge would (also) require one-sixth of the world's cropland. The technology for cellulosic ethanol is still being developed (though recent evidence looks promising); other problems include that the raw materials would otherwise be plowed back into the land, and plantations to secure the materials may expand into currently marginal areas, further reducing biodiversity in the remaining wild spaces of the planet (p 299)

Lynas suggests seven wedges which would keep emissions constant at 7 GtC:

- Energy efficiency: Halve driving distances per vehicle; double vehicle fuel efficiency; increase energy efficiency in buildings; and in fossil-fueled power stations
- Energy technology: Wind turbines; solar panels (PV on roofs preferred); make difficult choice between coal-CCS and replacing coal with gas power stations
- Land management: Stop deforestation and promote reforestation (his top preference).

To reduce emissions to ensure a $+2^{O}$C target, Lynas suggests the following additional wedges:

- Energy efficiency: Live less consumptive lifestyles; adopt more localized patterns of behavior
- Double quantity of wind turbines.

Naturally, many other options will be put forward, and the list will change as some technologies achieve greater technical and economic breakthroughs than others, and with the shifting balance between energy technology, energy efficiency, and land management options.

The current tendency seems to be to recommend technological solutions first, and look at energy efficiency options last. Lifestyle is, however, a prominent feature of the four scenarios, embedded in the original IPCC storylines. The extent to which populations can be persuaded to modify their lifestyles, or in the case of the main emerging countries such as China, India, other Asian countries, Brazil and other Latin American countries, and the emerging eastern European economies, to refrain from copying the current lifestyles of rich countries, has to be carefully considered. Current indications are that western lifestyles will be copied.

## REVIEW OF TECHNOLOGIES

This review comes from a variety of sources and does not claim to be exhaustive, just to. give a reasonably meaningful description in a limited space. The starting point is Jacobson (2009), followed by Goodall's *Ten Technologies to Save the Planet* (2008) and other sources, including those describing the history of particular technologies. They show that many years can elapse between the discovery of a natural *phenomenon* and the *invention* leading to the development and commercial integration of a technology (Arthur 2009). The technologies are divided into the Cosier (2009) headings of energy technologies, geoengineering options (headlined separately because they represent a different magnitude of potential energy technologies), energy efficiency measures, and landscape (land) management, including coastal management as a separate category.

### ENERGY TECHNOLOGIES

#### *Solar photovoltaics (PVs)*

The photovoltaic effect is the operating principle of the solar cell, in which the capture of light (photons) results in the creation of an electric current as electrons are transferred from one material to another resulting in the build-up of a voltage between two electrodes. It was discovered in July 1839 by then 19-year old Alexandre-Edmond Becquerel, who reported his findings to the French Academy of Sciences later in that year.[102]

Charles Fritts, an American, described the first solar cells made from selenium wafers in 1883. It was 1954 before Bell Laboratories made the first PV device providing useful amounts of electricity, and early 2000s before PVs experienced rapid commercial growth, rapid cost reduction, and large technological breakthroughs.[103] The payback period has halved and thin-film panels have even better energy balance because they require much less energy to produce (Goodall 2008, p 59). The technology is versatile because panels can be mounted in small numbers on roofs or combined into farms ranging from 10-60 MW capacity. The largest problem – shared with other technologies according to Goodall – is scaling up the manufacturing rate to make a sizeable dint in global greenhouse emissions in time (p 58). But he notes that the scope for unexpected and truly revolutionary advances in PV technology is at least as great as for any other technology he examined.

[102] Wikipedia, 'A. E. Becquerel', as at February 27, 2010.

[103] http://www.sunlightelectric.com/pvhistory.php.

***Concentrated solar power (CSP)***

In the 1860s, French mathematician August Mouchet proposed an idea for solar-powered steam engines. In the following two decades, he and Abel Pifre constructed the first solar powered engines and used them in a variety of applications. These engines became the predecessors of modern parabolic dish collectors. In 1969, the Odeillo solar furnace in southern France was constructed, featuring an eight-storey parabolic mirror. However, it was not until the 1980s that the first large-scale solar thermal electric generators were built.[104]

Concentrated Solar Power is now undergoing a renaissance in the solar-rich areas of the world including Spain and the United States Southwest, according to Emerging Energy Research (EER), which analyzes clean and renewable energy markets on a commercial basis. EER notes that solar CSP is the fastest growing utility-scale renewable energy alternative after wind power, with up to $20 billion expected to be invested in the technology over the next five years.[105] In the US Southwest, utilities are showing increasing interest in the deployment of CSP plants to meet the requirements of state renewable portfolio standards (DOE 2009).[106]

As at early 2010, there is 679 MW of installed CSP capacity worldwide and more than 2000 MW under construction. The US is the market leader in terms of installed capacity with 63% market share, followed by Spain with 32% of operating capacity. Spain accounts for the largest share of projects under construction with almost 89%, and may topple the US as global leader in installed CSP capacity by 2013 (Torres et al. 2010).

Other areas attracting attention as potential CSP sites include the Middle East and North Africa ("MENA"), as well as India, Australia and China. The two latter countries are reported to be investigating the combination of CSP and biomass technology, using the high heat generated by the CSP plant to break down biomass such as algae into hydrocarbon fuel and chemicals. This would help bypass first-generation biofuels such as food plants, going straight to more acceptable sources.

The Australian National University in Canberra has worked for many years on parabolic dish solar concentrators and demonstrated a 400$m^2$ parabolic dish solar system in 1994.

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[104] http://www.rise.org.au/info/Tech/hightemp/index.html. CSP, as discussed in the current section, covers large high-temperature systems. Solar thermal systems also include generally much smaller low- and medium-temperature systems for swimming pool, domestic hot water and space heating, and in passive solar building design.

[105] From http://www.emerging-energy.com/, as at October 2009. The website keeps changing and much material is exclusively available for the company's clients, including comprehensive recent reports on the USA and Europe. Other information sources provide an ongoing review of new developments, including *CSP Today* which offers free newsletters and a free summary of a high-priced global analysis (Torres et al. 2010). The summary provides an adequate picture for our purposes.

[106] Florida Power & Light (FPL) began construction in its home state at the Martin Next Generation Solar Energy Center in Indiantown, western Martin County, in December 2008, with completion expected at the end of 2010. It is the first hybrid solar facility in the world to connect to an existing combined-cycle power plant and at 75 MW will be the largest solar thermal plant outside of California. The annual generation is expected to be about 155,000 MWh or enough power for 11,000 homes (http://www.fpl.com/environment/solar/martin.shtml).

Commercializing the “Big Dish” technology involved a re-design of the concept for mass production, undertaken after a partnership was brokered in 2005 between the university’s Solar Thermal Group and the solar technology firm Wizard Power, also located in Canberra. Construction of a first prototype on the ANU campus began in the first quarter of 2008, and initial tests were carried out in June 2009 (Lovegrove et al. 2009).

Wizard Power’s attempts to commercialize several solar-biofuel processes are also based on ANU research work. The Big Dish technology can create maximum temperatures of over 2000°C, with a typical operating range of 400-1400°C. However, the jury remains out whether to develop solar-biofuel technology in conjunction or commercialize at least one of the two technologies first (Wagg 2010).

A German consortium is studying the feasibility of building a collection of CSP plants in North Africa and Saudi Arabia, which could meet 15% of Europe’s electricity needs by 2050. The project, called Desertec, plans to transmit the electricity via 20 high-voltage DC power lines across to Europe, where it would join a supergrid conveying power from North Sea wind turbines, [107] Scandinavian hydroelectric dams, Icelandic hot rocks, and eastern European biofuels. The major problems are water supply for heat exchange (air cooling is less efficient and more expensive), and supply security.

A Nigerian entrepreneur has set up an organization to promote the use of African sunshine for Africans (Pearce 2009).

While PV cells convert photons directly from sunlight into electricity, CSP technology generates power from the sun by concentrating the rays on to a liquid. “The best established solar thermal technology … uses long parabolic troughs covered with reflective material to concentrate the sun’s powers on to a thin tube, called a receiver, in the center of the parabola. A good solar collector can focus about a hundred times the power of the sun on to this receiver. The tube contains water or, more usually, oil, which is heated to over 400$^{O}$C in full sun. The hot oil is passed through water, with which it exchanges heat. The water rapidly heats up, boils, and then turns into electric steam, ready for powering a rotating turbine, in exactly the same way as it would in a coal-fired power station.” (Goodall 2008, p 60)

There are four primary CSP plant designs (described in DOE 2009, Pearce 2009, and elsewhere). The description below is mainly from Wikipedia, as at March 2010:

- **Parabolic solar trough designs** described in the previous paragraph. The main existing plants in California, Nevada, and Spain are of this type.
- **Power towers** use an array of flat, moveable mirrors, called heliostats, to focus the sun's rays upon a collector tower (the receiver). The prototype plant is in Spain but several new projects are being planned or constructed in Southern California including the

[107] The wind and hydropower components have moved closer to reality with the formation, on March 8, 2010, of “Friends of the Supergrid” (FOSG), initiating a $46 billion project to progress policy towards the construction of a pan-European offshore supergrid. The initial participants are 10 major global corporations based in Europe (FOSG 2010). The project links up with a recent decision by nine northern and western EU member states (the UK, Ireland, Norway, Denmark, Germany, the Netherlands, Belgium, Luxembourg, and France) to sign a political declaration for the "North Seas Countries Offshore Grid Initiative". The German company Siemens is a prominent member of both the FOSG and Desertec projects.

largest solar power commitment ever made by a utility (the Pacific Gas and Electric Company), and in Israel, Spain, and South Africa.

- **Linear Fresnel** reflector power plants use a series of long, narrow, shallow-curvature (or even flat) mirrors to focus light onto one or more linear receivers positioned above the mirrors. These systems aim to offer lower overall costs through simpler design. The Fresnel solar power plant PE 1 of the German company Novatec Biosol went into commercial operation in southern Spain in March 2009 with an electrical capacity of 1.4 MW; a recent prototype in Australia has led to a proposed 177MW plant near San Luis Obispo in California; a Belgian prototype has generated several other prototype projects.
- **Dish/engine systems** produce electricity directly from heat using a large parabolic disc, usually in combination with a Stirling engine (an external combustion engine that isolates its working fluid from the energy input supplied by an external heat source). Disc systems can generate high temperatures from high concentrations of light. Two Californian power companies have announced agreements to purchase solar-powered Stirling engines to generate power plants between 300 and 900 MW, but it is unclear whether the technology has progressed beyond the construction of a small test plant.

All designs use a small amount of water for mirror cleaning, and all except dish/engine systems operate a steam cycle which require water for steam makeup and then a substantial amount of water for heat rejection, similar to water-cooled fossil and nuclear plants.

Water cooling is preferred to minimize cost and maximize cycle efficiency, but there are concerns about mounting water shortages and air pollution. "Analyses indicate that the use of either direct or indirect dry cooling can eliminate over 90% of the water consumed in a water-cooled concentrating solar power plant. However, a combination of a reduction in power output and the added cost of the air cooling equipment is estimated to add roughly 2 to 10% to the cost of generating electricity, depending on the plant location and other assumptions. The use of hybrid parallel wet/dry cooling is estimated to reduce the energy cost penalty to below that of air cooling alone, while still saving about 80% of the water compared to a water-cooled plant." (DOE 2009, p 19). The technology continues to develop.

***Wind energy***

Wind technology has evolved through the entire recorded history of humankind, from the Fertile Triangle and India in the second millennium BC. Much later, small windmills for mechanical loads such as pumps and mills showed rapid growth in the 19th century.

The modern incarnation is the wind turbine, first built for electricity generation in 1986 and 1987 in Cleveland, Ohio, and Scotland. In the 1890s a Danish scientist, Poul la Cour, constructed wind turbines to generate electricity, which was then used to produce hydrogen. Wind farms were given a boost when long-distance electric power transmission became available and the wind generators no longer had to be built next to where the power was needed. Through the 20th century the technology developed in many countries, with Denmark in a leading position, including the development of offshore wind farms, and the first nation to derive a significant fraction of its electricity from that source.

Installed wind power capacity increased rapidly and steadily from 59 GW in 2005 to 158 GW in 2009 (+168%). The European Union accounted for 41 GW in 2005 and 75 GW in 2009, and the United States for 9 GW and 35 GW, respectively, according to the World Wind Energy Association. Wind power in 2008 accounted for 19% of stationary electricity production in Denmark, 13% in Spain and Portugal, and 7% in Germany and Ireland. Eighty countries around the world used wind power on a commercial basis in May 2009.

The main drawback of wind power is its intermittency, though this is less likely to cause problems when wind covers a relatively low proportion of total demand. New projects are often restricted locally or even on a national basis, due to their visual impact and effect on the environment. [108]

The efficiency of wind power generation increases with the turbine height since wind speeds generally increase with increasing height. So larger turbines capture faster winds and are generally sited in flat open areas of land, within mountain passes, on ridges, or offshore. Although less efficient, small turbines (1–10 KW, compared with 1 to 2 MW for typical wind farm turbines) are convenient for use in homes or city street canyons (Jacobson 2009).

Conservatively estimated, 13% of all stations worldwide have an annual mean wind speed above 6.9 m/s at 80 m (ranked as “Class 3” or greater), and are therefore suitable for wind power generation. Europe and North America have the greatest number of stations in class ≥3 (307 and 453, respectively), whereas Oceania and Antarctica have the greatest percentage (21 and 60%, respectively). Areas with strong wind power potential are in northern Europe along the North Sea, the southern tip of the South American continent, Tasmania, the Great Lakes region, and the northeastern and western coasts of Canada and the United States. Offshore stations experience mean wind speeds at 80 m that are about 90% greater than over land (Archer and Jacobson 2005).

### *Geothermal energy*

Geothermal energy is extracted from hot water and steam below the Earth’s surface. Hot springs were used through antiquity. Geysers and other underground sources have been used historically to heat buildings, industrial processes, and domestic water.

Modern geothermal technology was made possible by Lord Kelvin’s invention of the heat pump as far back as 1852, and the idea of using it to draw heat from the ground was patented in Switzerland in 1912. But it was not until 1940s that the idea was successfully implemented. The first commercial geothermal heat pump for a commercial building was designed in 1946, and the first residential heat pump two years later. The technology became popular in Sweden after the 1973 oil crisis, and has been growing slowly in worldwide acceptance since then. The development of polybutylene pipe in 1979 greatly augmented its economic viability. By 2004 over a million geothermal heat pumps were installed worldwide providing 12 GW of thermal capacity. Each year, about 80,000 units are installed in the USA and 27,000 in Sweden.

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[108] Main source: Wikipedia on wind power, accessed most recently on March 11, 2010.

Even in regions without large high-temperature geothermal resources (as exist in Iceland and the Cooper Basin in Central Australia),[109] a geothermal heat pump can still provide space heating and air conditioning. Like a refrigerator or air conditioner, the heat pump forces the transfer of heat from the ground to the application. In 2004, an estimated million geothermal heat pumps with a total capacity of 15 GW extracted 88 petajoules of geothermal energy for space heating. Global geothermal heat pump capacity is growing by 10% annually. [110]

Dry steam, flash steam, and binary are three major types of geothermal plants. Dry and flash steam plants operate where geothermal reservoir temperatures are 180–370$^0$C or higher. In the dry steam plant, about 70% of the steam re-condenses after it passes through a condenser, and the rest is released to the air. Since carbon dioxide, nitric oxide (NO), sulfur dioxide ($SO_2$) and hydrogen sulfide ($H_2S$) in the reservoir steam do not re-condense along with water vapor, these gases are emitted to the air. In a flash steam plant, the liquid water plus steam from the reservoir enters a flash tank held at low pressure, causing some of the water to vaporize (''flash''). The vapor then drives a turbine. About 70% of this vapor is re-condensed. The remainder escapes with $CO_2$ and other gases.

A binary system is used when the reservoir temperature is 120–180$^0$C. Water rising up a borehole is kept in an enclosed pipe and heats a low-boiling-point organic fluid, such as isobutene or isopentane, through a heat exchanger. The evaporated organic turns a turbine that powers a generator, producing electricity. Because the water from the reservoir stays in an enclosed pipe when it passes through the power plant and is re-injected to the reservoir, binary systems produce virtually no emissions of $CO_2$, NO, $SO_2$, or $H_2S$. About 15% of geothermal plants today are binary plants (Jacobson 2009).

***Hydroelectricity***

Hydroelectric power is old and tested technology. It is currently the world's largest installed renewable source of electricity, supplying about 17.4% of total electricity in 2005. Water generates electricity when it drops gravitationally, driving a turbine and generator. While most hydroelectricity is produced by water falling from dams, some is produced by water flowing down rivers (run-of-the-river electricity). Hydroelectricity is ideal for providing peaking power and smoothing intermittent wind and solar resources (Jacobson 2009).

Hydroelectric production, however, is very sensitive to changes in precipitation and river discharge, which is important in conditions of climate change in areas, like some regions in the United States, that derive a significant part of their electricity demand from this source. "For example, every 1% decrease in precipitation results in a 2 to 3% drop in streamflow; every 1% decrease in streamflow in the Colorado River Basin results in a 3% drop in power generation. Such magnifying sensitivities occur because water flows through multiple power plants in a river basin." (Karl et al. 2009, p 59)

As an addendum to the two previous sections, Iceland uses an extraordinary combination of energy resources, enabling it to be 81% self-sufficient in renewable energy: 66% of primary

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[109] Flannery (2009), chapter on "Geothermia".

[110] Wikipedia, "Geothermal heat pump".

energy use from geothermal and 15% from hydropower in 2008 (the remaining 19% was overwhelmingly oil, very little coal). Geothermal energy comes from 27 high-temperature geothermal fields and a large number of low-temperature fields, across the island. In 2008 it was used for space heating (48%), electricity generation (37%), and other purposes (15%). Heating from renewable sources basically used geothermal energy, while hydroelectric power was mainly for electricity generation. An extraordinary high proportion of total electricity usage went into aluminum production. Other renewable energy sources, including wind power, were practically non-existent in Iceland (Eggertson et al., 2009).

### *Wave energy*

The first patents for wave-power devices were issued in the 19th century, and by 1966 the French had built a tidal barrage power station at La Rance River, with an annual production of 600 GWh, which is still operating today (Esteban et al. 2008). Work on wave energy began in earnest only in the early 1970s as a response to the oil crisis. Several government-sponsored programs throughout the world included Japan, Norway and the United Kingdom. These programs advanced the technology considerably and their achievements were impressive, but prototype programs failed to deliver economic supplies of electricity, leaving the technology with a credibility problem that has been hard to overcome.[111]

Winds passing over water create surface waves. The faster the wind speed, the longer the wind is sustained, the greater the distance the wind travels, and the greater the wave height. The power in a wave is generally proportional to the density of water, the square of the height of the wave, and the period of the wave.

Wave power devices capture energy from ocean surface waves to produce electricity. One type of device is a buoy that rises and falls with a wave, creating mechanical energy that is converted to electricity that is sent through an underwater transmission line to shore. Another type is a floating surface-following device, whose up-and-down motion increases the pressure on oil to drive a hydraulic ram to run a hydraulic motor (Jacobson 2009).

### *Tidal energy*

This technology has ancient origins. The earliest evidence of the use of oceanic tides for power conversion dates back to the early Middle Ages and possibly even earlier. Tide mills were specialist water mills driven by the tidal rise and fall. Early tidal power plants utilized naturally-occurring tidal basins by building a barrage (dam) across the opening of the basin and allowing the basin to fill on the rising tide, impounding the water as the tide fell, and then releasing the impounded water through a waterwheel, paddlewheel or similar energy-conversion device. The power was typically used for grinding grains into flour. Power was available for two to three hours, usually twice a day.

Tidal turbines draw energy from currents in much the same way as wind turbines do from air. A generator in a tidal turbine converts kinetic energy to electrical energy, which is transmitted to the shore. The turbine is generally mounted on the sea floor and may or may not extend to the surface. The underwater rotor may be fully exposed to the water or placed

[111] http://www.wave-energy.net/Schools/History.htm.

within a narrowing duct that directs water toward it. Since tides run about six hours in one direction before switching directions for six hours, they are fairly predictable, so tidal turbines are potentially useful base load energy (Jacobson 2009).

The potential for power generation by an individual tidal turbine can be greater than that of similarly rated wind energy turbine. The higher density of water compared to air means that a single generator can provide significant power at low tidal flow velocities, compared with wind speed.

The first commercial-scale modern-era tidal power plant was built in 1965 near St. Malo, France. The tidal barrage at St. Malo uses 24 highly efficient 10-MW turbine generator sets. The barrage has been functioning without missing a tide since being constructed.

The second commercial-scale tidal barrage plant was put into service at Annapolis Royale, Nova Scotia, Canada in 1982. This 16-MW turbine had some teething troubles, but has been functioning without interruption since its early days.

The grandest project of all was the 8,640-MW Severn Tidal Barrage (STB) proposal. A broad range of studies was conducted from 1974 to 1987 on this proposal to dam the Severn Estuary between Wales and England. The tidal range in the Severn is up to 40 feet in places and the potential power from a barrage could provide 12% of the United Kingdom's requirements. Major engineering consultancies, large construction companies, several universities, and the UK Government's Department of Trade and Industry combined to fund and conduct the 13 years of studies costing almost $100 million.

The STB proposal was shelved in 1987 due to "economic problems," but the proposal most likely would have met with fierce opposition from a broad array of environmental groups and local inhabitants. Tidal barrages across inlets or estuaries suffer from four types of environmental problems, which will continue to work against the technology:

1. Barrages block navigation. Locks can be installed to allow some traffic, but it is a slow and costly alternative to free access to the ocean.
2. Barrages impede migration of fish which spawn in fresh water, migrate to salt water, then return after three or four years to spawn and die, drawn to the exact location of their birth. They may pass through the turbines but the mortality rate is about 6%.
3. Barrages change the size and location of the intertidal zone. The alternating wet and dry intertidal zone is unique and only certain types of plants and creatures thrive there. The barrage affects the tidal cycle and changes the water levels, obliging the plant and animal life to adapt to the new location. The functioning of the barrage may be limited to maintain the water at nearly normal levels, but with a high loss of potential output.
4. Barriers change the tidal regime downstream. Canada's Bay of Fundy has the largest tidal ranges in the world and has been the subject of numerous studies of proposed tidal power plant installations. Models of the effects of the huge proposed barrages suggest that the highest tides downstream might be raised as much as nine inches right down to Boston, 800 miles away. Even the possibility of such an impact was considered sufficient

to draw lawsuits from every property owner with a flooded basement from Nova Scotia to Cape Cod.[112]

***Fuel cells***

Fuel cells link into a long line of hydrogen history going back to the discovery of that element in 1625. The fuel cell was invented by German-Swiss chemist Christian Friedrich Schönbein in 1838 (he discovered and named ozone two years later). Welsh lawyer and scientist Sir William Grove developed a fuel cell between 1839 and 1842, which produced electrical energy by combining hydrogen and oxygen.

The first commercial use of fuel cells was through General Electric (developed by W. Thomas Grubb) in cooperation with NASA and McDonnell Aircraft, leading to its use in Project Gemini in the mid-1960s. In 1959, a 15 kW fuel cell tractor for Allis Chalmers was demonstrated across the United States at state fairs. United Technologies Corporation through its subsidiary UTC Power was the first company to manufacture a large, stationary fuel cell system for use as a co-generation power plant in hospitals, universities, and large office buildings. The company is also the sole supplier of fuel cells to NASA as well as developing fuel cells for automobiles, buses and cell phone towers.

Fuel cells come in at least 20 varieties but they all work in the same general manner. They are made up of three segments which are sandwiched together: the anode, the electrolyte, and the cathode.

At the anode a catalyst oxidizes the fuel, usually hydrogen, turning it into a positively charged ion and a negatively charged electron. The electrolyte is a semi-porous substance designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electrical current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electrical current is created which can be used to power electrical devices. [113]

Despite its long history, the technology has struggled in the competition with other energy sources and has not reached its full potential. The most promising application according to Goodall (2008) is in providing combined heat and power, one of his “ten technologies to save the planet.” He notes that several firms are making good progress in constructing fuel cells for generating electricity and heat on a domestic scale. The advantage of this is that while a pack of fuel cells assembled into a home power plant is about 50% efficient in generating electricity from, say, natural gas, about two-thirds of the heat generated from the plant can be used to heat the home. This means the device can capture 85% of the total energy of the gas, which is better than the capability of a new large-scale gas power station (pp 104-105).

[112] http://tidalelectric.com/History.htm. Chapter 3 of Esteban et al. (2008) provides a useful and more specific review of ocean energy (tidal and wave).

[113] Wikipedia, ‘Fuel cell’, most recently accessed March 11, 2010.

Other manufacturers supply larger units, delivering more than 1 MW capable of powering an office block or shopping mail. They also typically convert about 50% of the chemical power of a fuel to electricity, and most of the rest to heat. The implications for urban district heating applications are discussed in the section on energy efficiency.

***Biofuels***

Biofuels are solid, liquid, or gaseous fuels derived from organic matter, traditionally from dead plants or animal excrement. Wood, grass, and dung are used directly for home heating and cooking in developing countries, and for electric power generation. These technologies have been around for centuries but recent developments dig deeper.

The genesis of biofuels for transportation is associated with two illustrious names. In 1898, Rudolf Diesel premiered the diesel engine at the World Exhibition in Paris to run on peanut oil. Henry Ford was also a key player in the early alternative fuels movement, beginning with his 1908 Model T engine to run on ethanol.[114]

Biofuels include biodiesel and bioethanol (the latter most commonly in blends with gasoline) from agricultural plants and from fermentation of lignocellulose, algae and cyanobacteria. Ethanol is produced in a distillery, usually from sugar cane, sugar beet, molasses, corn, or wheat. Microorganisms and enzymes ferment sugars or starches in these crops to produce ethanol.

The conflict caused by diverting food into energy resources in the United States, Brazil and other countries[115] is being discussed at length as a legitimate concern, but adding other feedstocks and the expansion of industrial biotechnology to replace the petrochemical routes is expected to be very rapid (Villadsen 2007). He advocates parallel research and teaching in the engineering fields that relate to processes where enzymes and living cells are used as “chemical factories”.  Industrial research using feedstock such as switchgrass, corn stover (leaves and stalks), sugar cane leaves, industrial waste, and algal oil, among others, shows promises of commercial feasibility.

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[114] http://www.nrpw.com/history.html.

[115] Brazil stands out as an apparent exception, due to abundant resources. It has been producing ethanol from sugar cane in increasing quantities since the 1970s, and is the world’s leading exporter and demonstrably more efficient than the other large producer, the United States, using mainly corn as feedstock. Production in Brazil grew from 3,989 million US gallons in 2004 to 6,472 million gallons in 2008, from just 1% of the total arable land (Wikipedia article on “ethanol fuel in Brazil”, most recently accessed on March 21, 2010). The ethanol program is based on indigenous technology, both industrial and agricultural. It is expected to develop other biomass-derived fuels including ethanol from cellulosic materials and enhanced use of biogas from conversion of waste materials (Goldemberg 2007).

The argument against growing sugar cane for ethanol in Brazil appears to be growing. One reason is that it contributes to deforestation in the Amazon. Though grown in the drier areas of the country, well away from the Amazon, this land use affects the supply and demand of land in the entire country (Goodall 2008, p 167). A $12 billion joint-venture agreement in February 2010 between Royal Dutch Shell and Brazilian sugarcane-to-ethanol producer Cosan is directed squarely towards using biomass for ethanol production. Shell is contributing its equity interests in two advanced biofuel developers, Codexis and Iogen. California-based Codexis is developing biofuel products to use as biocatalysts to convert biomass into fuel. Canada-based Iogen is developing a cellulosic biomass-to-ethanol conversion process that combines thermal, chemical and biochemical techniques, which will enable a wider range of biomass to be converted into fuel (Waltz 2010).

Production of ethanol and biodiesel from agricultural crops has been shown to increase atmospheric emissions of nitrous oxide ($N_2O$), which is a by-product of nitrogen application in agriculture and a powerful greenhouse gas (Crutzen et al. 2008).

Crops with less nitrogen demand, such as grasses (including sugar cane) or woody coppice species, have more favorable impacts on the climate. Production of ethanol from lignocellulose has the advantage of abundant and diverse raw material compared with sources like corn and cane sugars, but requires a greater amount of collection and processing to make the sugar monomers available to the microorganisms that are typically used to produce ethanol by fermentation. Switchgrass (*Panicum virgatum*) and the perennial grass genus *Miscanthus* are among the major biomass materials being studied today, due to their high productivity per acre.

Costs are coming down dramatically. In the span of less than a decade the enzyme costs of making ethanol from starch has decreased by a factor of at least five, and cost of enzymes (or other bio-based methods for liquefaction of the cellulose) for converting corn leaves and stalks or straw to fermentable sugars has come down by a factor of more than 10. “There is a distinct hope that second-generation ethanol production will become a viable process in the competition with fossil transportation fuels.” (Villadsen 2007) The main tools used are either enzyme engineering (improving the action of a specific enzyme) or the genetically engineered modification of a microorganism to improve the productivity of a given desired product.

Algae are proving a potentially useful source of biodiesel. Exxon Mobil’s program to improve energy efficiency has until recently concentrated on automotive technology, but in 2009 it announced a plan to invest up to $600 million into algae technology, half of which will fund the research company Synthetic Genomics Inc. Photosynthetic algae such as single-celled “microalgae” and blue-green algae use sunlight to convert $CO_2$ into cellular oils and some long-chain hydrocarbons that can be processed into fuels and chemicals (DOE 2009b).

Other large petroleum companies are exploring this technology, including Shell investing in a new venture in Hawaii in 2007, where a start-up company is creating large tanks of open-air algae in coastal lagoons for eventual conversion into biodiesel (Goodall 2008, p 203).

Smaller ventures are also starting up, including Aurora Biofuels in Florida, which had operated a pilot plant for 18 months by 2009 and expects to go commercial in 2012 (DOE 2009b). San Francisco-based Solazyme Inc. specializes in algal synthetic biology. In a recent brochure it offers “compelling solutions to increasingly complex issues of fuel scarcity, energy security and environmental impact while fitting cleanly into the pre-existing multi-trillion dollar fuel infrastructure.” [116]

Goodall (2008) mentions other ventures and raises the question whether this type of “biofixation” will ever be economically successful on a large scale (p 204). Prospects for this happening are, however, viewed optimistically by the venture capitalists driving the development, and the technology is expanding rapidly supported by continued scientific research, while costs have declined rapidly. Apparent advantages include that it does not

[116] http://www.solazyme.com/. The companies mentioned are examples only; there are many other ventures.

encourage deforestation, nor does it use a large amount of energy for growth and refinement of its products.

Furthermore, the commercial future of small-scale ventures is potentially attractive because it plays straight into the issue of technology diffusion, discussed in the concluding section of this appendix. Dispersion can be into all sort of directions, whether in the developed or the developing world, although the emphasis in our final section is on the latter.

***Coal – carbon capture and storage***

Carbon capture and storage (CCS) is the diversion of $CO_2$ from emission sources to underground geological formations (such as saline aquifers, depleted oil and gas fields, and coal seams that cannot be mined), the deep ocean, or as carbonate minerals. It is subject to many government-sponsored investigations including a task force established in February 2010 by the Obama administration works towards a comprehensive federal strategy on CCS (Peridas 2010).

Geological formations worldwide may store up to 2,000 Gt $CO_2$, which compares with a fossil-fuel emission rate today of an annual rate of about 30 Gt $CO_2$. To date, $CO_2$ has been diverted underground following its separation from mined natural gas in several operations and from gasified coal in one case. However, no large power plant currently captures $CO_2$.

Several options of combining fossil fuel combustion for electricity generation with CCS technologies have been considered, and more are likely to be added given the prominence given to the technology. In one model, integrated gasification combined cycle (IGCC) technology would be used to gasify coal and produce hydrogen. This model (with capture) is not currently feasible due to high costs.

In a more standard model, CCS equipment is added to an existing or new coal-fired power plant. $CO_2$ is then separated from other gases and injected underground after coal combustion. The remaining gases are emitted to the air.

Other possibilities include injection to the deep ocean and production of carbonate minerals. Ocean storage, however, results in ocean acidification. The dissolved $CO_2$ in the deep ocean would eventually equilibrate with that in the surface ocean, increasing the back-pressure, expelling $CO_2$ to the air – unless the $CO_2$ reacts with calcium ($Ca^{++}$) to form calcium carbonate ($CaCO_3$). Producing carbonate minerals has a long history. Joseph Black, in 1756, named carbon dioxide ‘‘fixed air’’ because it fixed to quicklime (CaO) to form $CaCO_3$. However, the natural process is slow and requires massive amounts of quicklime for large-scale $CO_2$ reduction. The process can be hastened by increasing temperature and pressure, but this requires additional energy (Jacobson 2009).

The Swedish utility Vattenfall, owned by the Swedish state, is considered a world leader in carbon capture. Starting research in 2001, it began constructing a 30 MW power station as a pilot plant next to its existing coal power station at Schwarze Pumpe in Germany. It began running in September 2008 and is the world's first coal-fired power plant to capture and store its own carbon dioxide emissions (Weiss et al 2008). But learning the lessons from this project will take years. Meanwhile, a larger demonstration plant is planned to start construction in 2010, with the intention to produce electricity by 2015.

Goodall concludes (2008, p 200 and 201): "Two decades is a sobering length of time, particularly since most other large utilities have barely started carbon capture feasibility studies. .. Governments are now beginning to realize that carbon capture offers significant prospects for carbon reduction, but that much research remains to be done." In short, capturing carbon through CCS at coal and gas power stations is a vital ingredient in any carbon reduction plan, but the technology is not yet sufficiently developed.

This is to put it mildly. "While capturing coal and disposing of it safely is the dream of the coal industry" which "has set up institutes, commissioned experts, lobbied governments and developed a slick marketing campaign to resuscitate the world's reputation of the world's dirtiest form of energy" (Hamilton 2010, pp 159-160), it has already been noted that no coal-fired power plants capture their carbon today, and large numbers of CCS-using plants are unlikely to be built within the next 20 years, and then at very high cost including the necessary comprehensive pipeline system.

Even the American Coalition for Clean Coal Electricity (ACCCE), with a membership of 48 coal and utility companies, has admitted that the commercialization and widespread use of CCS is still 10 to 15 years away – meanwhile, the organization lobbies against the introduction of global warming pollution reductions until the clean coal technology is ready. The Center for American Progress estimates that ACCCE spent at least $45 billion in 2008 to convince Americans that "clean coal" is the solution to climate change, and the coal mining and electric utility industry industries spent over $125 billion in the first nine months of 2008 to lobby Congress (Weiss et al. 2008).

The Center for American Progress also found that the combined profit of the 48 ACCCE members in 2007 was $57 billion, while they invested only $3.5 billion in CCS research in the five years to 2007 (Weiss et al. 2008). A similar reluctance to invest in their own alleged future was noted in Australia which is the nation with most to lose if coal mining was to end. The Australian industry funding for CCS funding is one-thousandth of its revenue, which may be compared with wool growers who allocate 2% of their sales to fund innovation (Hamilton 2010, pp 161-162).

The coal industry wants these systems to be predominantly publicly funded. The following is from the World Coal Institute (2009), an international organization of coal producers and stakeholders: "Current deployment rates for all low-carbon technologies are inadequate to reach government mitigation targets. In particular, current CCS deployment is too slow to allow necessary global GHG emissions reductions goals to be achieved. There is an urgent need to fund demonstration projects and that funding needs to come from both governments as well as a robust carbon market.

While there are a litany of issues that are often cited as barriers to CCS, the private sector cannot proceed with a deployment program on its own. The real barriers to widespread CCS deployment are not technological, they are political and financial.

This report concludes that although responding to global warming is expensive, CCS massively reduces the cost of an effective climate change response. In a post-2012 world, government policies need to include CCS as the costs for deploying CCS are at least comparable to, and in many cases better than, the costs for deploying other low carbon technologies." (p 3)

For concluding notes on the above discussion, see the section below on "geoengineering as a political crutch", which debates the penchant in some government and business circles to want to explore large-scale technological "cures" for atmospheric $CO_2$ pollution. It identifies Hamilton (2010) – and *The Economist* which he quotes – as effectively including CCS technology as another political crutch, an excuse for not going ahead more vigorously with more readily available renewable technologies.

## NUCLEAR ENERGY

This group of technologies has received increased attention in recent years as climate change has become recognized as increasingly risky and nuclear energy appears to be solving at least some of its safety, security, and waste management problems. Also, conventional fission technology is no longer the only approach that is being seriously studied – there is significant research into fusion, and into the possible combination of fission and fusion into hybrid reactor technology. While some of these possibilities are not expected to become commercial until the second half of the century, it could happen within the time horizon adopted for this report.

### ***Nuclear fission***

Nuclear fission plants produce electricity by splitting heavy elements. As mass is lost in the process, energy is released in accordance with the central mass-equivalence formula in Einstein's special theory of relativity, $E = mc^2$, where E is energy, m is mass, and c is the speed of light. The energy power of the fission process ($\Delta E = \Delta m \times c^2$) is transferred as kinetic energy to the fission products (such as neutrons).

The most common heavy elements split are uranium-235 ($^{235}U$) and plutonium-239 ($^{239}Pu$). When a slow-moving neutron hits $^{235}U$, the neutron is absorbed, forming $^{236}U$, which splits, for example, into $^{92}Kr$, $^{141}Ba$, three free neutrons, and gamma rays. When the fragments and the gamma rays collide with water in a reactor, they convert kinetic and electromagnetic energy to heat, boiling the water. The fragments decay further through radioactivity, emitting beta particles (high-speed electrons).

Uranium is stored as small ceramic pellets within metal fuel rods. After 18-24 months of use as a fuel, the useful energy is consumed and the fuel rod becomes radioactive waste that needs to be stored for up to thousands of years. However, with breeder reactors (see below), unused uranium and its product, plutonium, are extracted and reused, greatly extending the lifetime of a given mass of uranium and reducing the waste (Jacobson 2009).

The science of atomic radiation, atomic change and nuclear fission was developed between 1895 and 1945, culminating during World War II when most development was focused on the atomic bomb. After 1945 attention shifted to harnessing the energy in a controlled fashion for naval propulsion and electricity generation. Since 1956 the main interest has been in the technological evolution of reliable nuclear power plants.

Nuclear energy was commercialized in 1959 and subsequent years in a number of countries: France, USA, UK, Canada, and the Soviet Union. From the late 1970s, the industry stagnated with the share of nuclear energy in world electricity production constant at 16-17%. By 2008 the share had fallen to 15% according to World Nuclear Association statistics.[117]

Despite the decline in the share of nuclear energy in the world's electricity production, the WNA is upbeat about the nuclear potential from fission. It notes a renaissance in third-generation reactors to meet projected worldwide electricity demand, particularly in China, India and South Korea. Increasing energy demand, increased dependence on overseas supplies of fossil fuels, awareness of the need for energy security, and the need to limit greenhouse gas emissions, have combined to make a case for increasing use of nuclear power (WNA 2009a, 2009c).

China is embarking upon a six-fold increase in nuclear capacity to 50 GWe (billion watts of electric capacity) by 2020; India's target is to add 20 to 30 new reactors by 2020. A global WNA projection shows at least 1,100 GWe of nuclear capacity by 2060, and possibly up to 3,500 GWe, compared with 373 GWe in 2008.

Breeder reactors generate new fissile material at a greater rate than it consumes such material. The naturally occurring heavy metal thorium is estimated to be three to four times more abundant than uranium in the Earth's crust. These reserves have the potential to power a planet-wide advanced civilization for an indefinite period (Sevior et al. 2010).

Production of fissile material in a breeder reactor is caused by neutron irradiation of fertile material, particularly uranium-238 and thorium-232. Thorium has a single stable isotope, $^{232}$Th and is safe, producing only one neutron per fission. In a nuclear reactor this isotope can capture a neutron and be converted to $^{233}$U. $^{233}$U undergoes fission like $^{235}$U and $^{239}$Pu. However, when $^{233}$U undergoes fission it releases more neutrons than either $^{235}$U or $^{239}$Pu. It is therefore possible to construct a breeder reactor using thermal neutrons to both generate energy and to breed $^{233}$U from thorium, given that sufficient initial quantities of $^{233}$U are mixed with $^{232}$Th (Sevior et al. 2010).

Concerns over safety and how to store large amounts of nuclear waste appear to be diminishing, and the plans reported above have been put forward despite a rising trend in construction costs for nuclear plants between 1970 and 2000 (corresponding to the period the industry stagnated according to the WNA). It exceeded the cost trends for other large infrastructure projects, such as major gas and coal power stations (Goodall 2008, pp 268-270).

Current nuclear plants are classified “generation II” or “generation III” (all first generation plants have been retired). Thermal and fast generation IV reactors have been under international review since 2002. They are expected to be highly economical with 100-300 times higher energy yields from the same amount of nuclear fuel, to be much safer, to produce nuclear waste that lasts decades rather than millennia, and to be able to consume nuclear waste when producing electricity. Most designs will not be available for commercial

[117] *World nuclear power reactors and uranium requirements as at February 1, 2010* – WNA table viewed March 12, 2010 at http://www.world-nuclear.org/info/reactors.html.

construction before 2030, with the exception of a version of a "Very High Temperature Reactor" called the "Next Generation Nuclear Plant". It is to be completed by 2021.[118]

In summary, nuclear fission technology appears destined to become more prominent. There is growing agreement that the world is ignoring the technology at its peril. [119] Meanwhile, the nuclear electricity generation's share in countries that chose a nuclear path is already far in excess of the 15% average, although the shares remained generally static between 1998 and 2008. France led the field in 2008 with 76.2% followed by Lithuania, Slovakia, Belgium, Sweden, Armenia, Switzerland, Hungary, and South Korea. The nuclear share was an above-average 19.7% in the USA, but remained at 2% in China and India. [120]

### *Nuclear fusion*

Nuclear fusion occurs naturally in stars, including our sun. What we see as light and feel as warmth is the result of fusion reaction: hydrogen nuclei collide, *fuse* into heavier helium atoms and release tremendous amounts of energy in the process.

Research into fusion for military purposes began in the early 1940s when scientists on the Manhattan Project investigated it as a method to build a bomb. Fusion was abandoned after concluding that it would require a fission reaction to detonate. It took until 1952 for the first full hydrogen bomb to be detonated, using reactions between the hydrogen isotopes deuterium and tritium. Fusion reactions are much more energetic per unit mass of fuel than fission reactions, but starting the fusion chain reaction is much more difficult. Research into controlled fusion for civilian purposes began in the 1950s, and continues to this day.[121]

The World Nuclear Association notes (2009b): "Fusion power offers the prospect of an almost inexhaustible source of energy for future generations, but it also presents so far insurmountable scientific and engineering challenges." There are, however, some promising developments which suggest that the technology may become commercial in the late 21st century. This includes the ITER project, which seven participating countries/unions[122] agreed to fund for 30 years in 2006: 10 years covering construction, 20 years for an operating stage. The plant is located in southern France. The plan is to start operating in 2018.[123]

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[118] Wikipedia, 'Generation IV reactor', as at March 13, 2010.

[119] NASA's James Hansen observes that renewable energies such as solar and wind have been gaining in economic competition with coal-fired plants, but would not be able to provide baseload power for years to come. "We should undertake focused research and development programs in next-generation nuclear power" (Dayton 2010). Bill Gates has spoken of five "energy miracles" needed to ensure "innovation to zero" (zero greenhouse gas emissions) by 2050. The five he selected are carbon capture and storage (CCS), nuclear fission, wind power, solar photovoltaic, and solar thermal energy. CCS, he says, is "a tough one", facing major issues of cost, location of dumps relative to plants, and long-term stability. Nuclear technology faces problems of cost, safety and proliferation, and long-term waste, but "should be worked on." The wind and solar technologies, facing problems of cost, transmission, and energy storage, are energy farming technologies needing lots of area, and their output is intermittent (Gates 2010).

[120] *Nuclear share figures 1998-2008* (WNA): http://www.world-nuclear.org/info/nshare.html.

[121] Wikipedia, 'Nuclear fusion', as at March 13, 2010.

[122] China, the European Union, India, Japan, Korea, Russia, and the USA.

[123] Griffith (2010). ITER was originally known as the International Thermonuclear Experimental Reactor, but the name was dropped in favor of the acronym because of the possible negative connotation of "thermonuclear".

ITER is based on the "tokamak" concept (a Russian acronym referring to the torus shape of the containing vessel) and is the world's largest of its kind, which it is hoped can be developed to the stage where it is possible to undertake magnetic confinement of the hot plasma. The fuel, a mixture of deuterium and tritium, is heated to temperatures in excess of 150 million degrees Celsius to form the plasma, which is contained in a torus- or doughnut-shaped double-walled vacuum vessel which provides a hermetically sealed plasma container. Strong magnetic fields would be used to keep the plasma away from the walls, produced by superconducting coils surrounding the vessel, and by an electrical current driven through the plasma.[124]

The objective of ITER is to demonstrate fusion as a future energy source, and form a bridge to large-scale production of electrical power and tritium fuel self-sufficiency. DEMO, standing for DEMOnstration Power Plant, is the next step after ITER. A conceptual design could be complete by 2017. If all goes well, DEMO will lead fusion into its industrial era, beginning operations in the 2030s, and putting fusion power into the grid as early as 2040.

"By the last quarter of this century, if ITER and DEMO are successful, our world will enter the Age of Fusion – an age when mankind covers a significant part of its energy needs with an inexhaustible, environmentally benign, and universally available resource." [125]

Hefei, 130 km west of Nanjing and capital of Anhui Province in China, is another significant nuclear research center which is currently taking an interest in hybrid nuclear reactors, discussed in the next section. Three important physics laboratories are located in Hefei including the National Laboratory for Nuclear Fusion (Tokamak) Research under the Institute of Plasma Physics, which is itself under the Chinese Academy of Sciences. [126]

The economist Nicholas Stern (2009, pp 112-113) has advocated that fundamental research priorities for climate change policy should cover a range of largely new and unproven technologies such as "energy storage, which encompasses research into different kinds of batteries (including nano-batteries), into storage through the creation and containment of hydrogen, into storage through lifting or heating of water, and so on. Other priorities include photovoltaics and new materials, new biofuels, enhanced photosynthesis *and nuclear fusion* [our emphasis]. There will be many more."

The timescale of ITER and subsequent nuclear fusion projects fits Arthur's (2009) hypothesis that the development of new bodies of technologies into commercial activities takes decades. If things go well, which they may not, an "age of fusion" may develop in the last quarter of the century. Even a "Manhattan Project" to accelerate the development of nuclear fusion technology may not change this greatly, giving priority to the introduction of nuclear fusion at a commercial scale over technologies that are starting to prove themselves, or could be supported to do so within, say, a decade. Stern's advocacy should be noted, however; he puts nuclear fusion in the same context as photovoltaics and biofuels, which are starting to spark large numbers of projects.

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[124] http://www.iter.org/mach/Pages/Tokamak.aspx.

[125] http://www.iter.org/proj/Pages/ITERAndBeyond.aspx.

[126] Wikipedia, 'Hefei', as at March 25, 2010.

### *Hybrid fusion reactors*

One problem with fusion is the size of the reactor core. To make a fusion reactor self-sustaining requires a plasma volume of about 3,300 $m^3$, more than three times the proposed volume of ITER. Another major unsolved problem is constructing a reactor wall capable of withstanding the intense bombardment of high-energy neutrons generated by the plasma. Hybrid nuclear power potentially solves both these problems by reducing the required size of the plasma volume and by reducing, by a factor of 50, the energy flux reaching the outer reactor wall (Hunt and O'Connor 2010).

Hybrid nuclear power has been discussed for decades (references in Kotschenreuther et al. 2009) but has not yet been explained to governments, industry, researchers, and the public. Combining the two forms of nuclear power, fission and fusion, in a single reactor minimizes the environmental impact, reduces risks, enlarges reserves of nuclear fuel, and is more flexible to operate (Hunt and O'Connor 2010). It also eliminates some of the waste problems of the nuclear industry and potentially helps rid the world of plutonium and other weapons-grade materials (Kotschenreuther et al. 2009).

Several research institutions are actively engaged in research into hybrid fusion technology, including the ITER participants, the Institute of Fusion Studies of the University of Texas at Austin, and the Institute of Plasma Physics in Hefei, China.

### *Conclusion: nuclear energy*

In conclusion, nuclear power, from fission and potentially from fusion or using hybrid fusion reactors, is almost certainly destined to become prominent in combating increasingly serious climate change, though only fission has yet become technically and commercially viable.[127]

## GEOENGINEERING

The inclusion of this topic recognizes a range of possible technologies with a different status from those discussed above. The definition of geoengineering adopted in this report provides a *possible* fallback position for particular circumstances arising in the future. It should be more a matter of "What can we do if things start to get really wrong?" than trying

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[127] A general note of caution is appropriate here: Burgeoning technological development in any field is bound to lead to a wealth of more or less soundly based business ventures which will be vigorously promoted, whether they relate to nuclear science or other new energy applications. What follows is just one example which may, or may not, prove to have real economic and technical potential. The informative and inspiring role that investment advisers play, and have a right to play, is acknowledged but naturally not all their information leads to commercial ventures.

In March 2010, the Internet was abuzz with advice on "the most profitable nuclear advancement in 50 years," in which "over the next six months, thanks to the unprecedented discovery of a "monster metal", one company is about to create a global energy monopoly." (http://www.angelnexus.com/o/web/19676?lloct=2). The "metal" is the white crystalline beryllium oxide (BeO), the thermal conductivity and melting point of which are both very high (http://en.wikipedia.org/wiki/Beryllium_oxide), whereas the common fuel used in nuclear fission reactors, uranium dioxide ($UO_2$), has low thermal conductivity which leads to a variety of fuel performance problems. The background is that nuclear engineers from Purdue University undertook an investigation of enhanced thermal conductivity oxide fuels, which involved mixing BeO with $UO_2$ (Latta et al. 2008). The research received funding from the Department of Energy as far back as 2002, and BeO has been used in nuclear applications since the dawn of postwar civilian nuclear research in 1945 (Solomon et al. 2006). A world monopoly of the oxide would be hard to achieve, judging from this information.

to visualize it as a possible alternative in its own right any time soon. The definition adopted for geoengineering covers solutions requiring a radical change in the adoption of climate change technology, and being outside or close to the boundaries of the plausible within the confines of the 21st century, and therefore largely outside the scenario-planning approach.

The scenario stories describe what would happen without mitigation, regardless of global temperatures and other consequences. Mitigation could conceivably include adopting a geoengineering technology to avoid entering decades of global economic decline.

The Royal Society in a report on the science, governance and uncertainty of geoengineering (Shepherd et al. 2009) distinguishes two main groups:

- Carbon dioxide removal (CDR) techniques remove $CO_2$ from the atmosphere, including land and coastal management methods treated as mainstream, rather than radical, technologies in this appendix. One CDR technology fitting our definition of geoengineering as a radical potential solution is ocean fertilization, which the Royal Society report says carries a high risk of unintended and undesirable ecological side effects (p 18). The report sees no potential for large-scale carbon dioxide scrubbers, which trap $CO_2$ from the air. [128] It is more upbeat about geoengineering proposals aimed at increasing the ability of the Earth's carbonate or silicate minerals to decrease emissions and atmospheric concentrations of $CO_2$. It sees the primary barriers to deployment as related to scale, cost, and possible environmental consequences (p 13).
- Solar radiation management (SRM) technologies aim at reflecting a small percentage of the sun's light and heat back into space. Possible techniques include increasing the albedo or reflectivity of (a) Earth's surface, (b) oceanic clouds, and (c) the stratosphere. Another possible technique is to reduce incoming solar irradiance through space-based installations, which as discussed below this is likely to remain prohibitively expensive.

The Royal Society's headline message (Shepherd et al. 2009, p ix) is clear: "The safest and most predictable method of moderating climate change is to take early and effective action to reduce emissions of greenhouse gases. No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change."

Some geoengineering methods are deemed potentially useful in future to augment continuing efforts to mitigate climate change by reducing emissions, and are "very likely to be technically possible. However, the technology to do so is barely formed, and there are major uncertainties regarding its effectiveness, costs, and environmental impacts."

***Geoengineering versus nuclear options***

The geoengineering options should be compared with the potential for fusion-based energy production. As outlined in the section on nuclear fusion, the technology remains difficult but projects are underway, including the DEMOnstration project planned to follow the current ITER project in the latter part of the 2010s. If this is successful, nuclear fusion could become

[128] A variety of scrubber called "artificial trees" has been advocated as a potentially lower-cost method of removing $CO_2$ from the air passing it over a substance such as sodium hydroxide, so that it combines with the chemical and can then be removed and stored underground. It is reported as being low-risk, potentially highly effective, and moderate to high cost, but a prototype is still five years away (Giles 2010).

a commercial reality sometime toward the end of the century. Hybrid fusion reactors may help pave the way for the technology.

The Royal Society report clearly considers that nuclear technology to be distinct from its subject of geoengineering solutions to climate change, and nowhere attempts to compare the two. Arguably, however, the potential of nuclear technology, including straight or hybrid fusion, is greater than any geoengineering option, at lower risk and probably at lower cost.

***Geoengineering politics***

Geoengineering has been defined as intentionally large manipulation of the natural global environment. It refers to technologies being proposed by some scientists and commercial journalists as a "politically realistic" remedy for climate change (Hall 2005). Governments tend to see it as a means of overcoming the problem of replacing fossil with renewable technology to reduce greenhouse gas emissions – a feeling temporarily reinforced by a disappointing outcome of the Copenhagen climate conference in December 2009. Despite the fact that most or all geoengineering technologies remain commercially unproven, the danger is that the assessment of some potentially massive environmental risks will be allowed to take a back seat to political convenience – even to the extent of postponing other action against climate change because "geoengineering will fix it". This is further discussed in the section below, called "geoengineering as a political crutch."

In September 2001, President Bush's Climate Change Technology Program convened a meeting to discuss "response options to rapid or severe climate change". Despite the fact that administration officials were then insisting publicly that there was no firm proof that the planet was warming, they were actually exploring potential ways to turn down the heat.

Reliance on a "technological fix" has permeated much political thinking, and it remains in the political line of sight, sufficient in March 2010 for the bipartisan US National Commission on Energy Policy to create a high-level task force to examine research and policy issues associated with geoengineering (Mandel 2010).

Robert Socolow, known for the "stabilization wedges" described in a previous section of this appendix, has issued a warning to be "very careful" when it comes to thrashing out guidelines for the "nascent field of geoengineering" (Tollefson 2010). Socolow highlighted the legal, moral and ethical quandaries of geoengineering to a research conference at the Asilomar Conference Center near Monterey, CA, in March 2010. Symbolically, the conference was held in the same location as a landmark conference in 1975 on the then budding field of genetic engineering – then regarded as frightening but since developing as a pivotal part of the burgeoning field of biotechnology.[129]

While participants generally agreed on the need to identify a responsible way ahead for geoengineering research, Socolow's cautionary note was clearly heeded according to Jeff Tollefson, the *Nature* journal reporter. One participant said, "We're scared, and nothing

[129] There is another possibility if we look another 30-35 years ahead. In a best-case scenario, biotechnology coupled with other technologies may have made decisive and economically efficient contributions towards the twin global problems of poverty and climate change. Geoengineering solutions, meanwhile, may still be regarded as too expensive and/or too environmentally risky.

brings people together like fear." Tollefson concluded: "It was evident from the beginning that the much broader field of geoengineering would not yield to simple principles as quickly as had genetics." The 2010 conference failed to come up with clear guidelines for geoengineering experiments.

In the United Kingdom, a memorandum of draft principles for the conduct of geoengineering research has been submitted to the Parliament (Rayner et al., 2009). Known as the "Oxford Principles" because the lead author and two of the four co-authors work there, it proposes five principles for the guidance of geoengineering research:

1. *Geoengineering to be regulated as a public good*: While private sector involvement in the delivery of a geoengineering technique should not be prohibited, and may even be encouraged in the interest of timeliness and efficiency, regulation of such techniques should be undertaken in the public interest at national and/or international level.
2. *Public participation in geoengineering decision-making*: Wherever possible, those conducting geoengineering research should be required to notify, consult, and ideally obtain the prior informed consent of, those affected by the research activities. Capturing carbon dioxide from the air and sequestering it geologically within the territory of a single state will probably require consultation and agreement only at the national or local level. A technique which involves changing the albedo of the planet by injecting aerosols into the stratosphere will most likely require global agreement.
3. *Disclosure of geoengineering research and open publication of results*: There should be complete disclosure of research plans and open publication of results to facilitate better understanding of the risks and to reassure the public as to the integrity of the process. It is essential that the results of all research, including negative results, be made publicly available.
4. *Independent assessment of impacts*: An assessment of the impacts of geoengineering research should be conducted by a body independent of those undertaking the research; such assessment should be carried out through the appropriate regional and/or international bodies if extending beyond boundaries. Assessments should address both the environmental and socio-economic impacts of research, including mitigating the risks of lock-in to particular technologies or vested interests.
5. *Governance before deployment*: Any decisions with respect to deployment should only be taken with robust governance structures already in place, using existing rules and institutions wherever possible.

These recommendations would appear to be the first submitted to a national political body and will undoubtedly be modified, including strengthening or weakening provisions that currently read somewhat loosely, as in expressions like "should", "wherever possible", "ideally" and other phrases that seem to play into the hands of a political process. Socolow's warning should be kept in mind in all contexts, including big business.

In January 2006, Australia, China, India, Japan, Korea, and the United States signed the Asia-Pacific Partnership on Clean Development and Climate. [130] At the time, Australia and the US were the only major countries that hadn't ratified the Kyoto Protocol, and the leaders of both countries publicly declared their faith in "technology" while remaining climate skeptics. The technology President Bush and then Prime Minister John Howard of Australia ended up espousing was carbon capture and sequestration (CCS), one part of the Royal Society's carbon dioxide removal (CDR) group which may no longer be considered "geoengineering" but has not yet proven itself as a large-scale technical solution.

At the September 2001 meeting of the Bush Climate Change Technology Program, the proposals included the following six technologies, rated for feasibility, cost, and risk in an anonymously written *Popular Science* article (Anon 2005). Some of these technologies were never serious contenders but give an idea of the range of options considered:

- Underground storage of carbon dioxide, rated 10 out of 10 for feasibility (the Weyburn project already exists in Saskatchewan, Canada), moderate on cost, and 4 on risk. The proposal differs from the coal-CCS technology. The $CO_2$ in question here is used in high-pressure form in an oil field to drive the oil to the surface. The risk is stated to be seepage of the carbon dioxide from its highly pressured state underground.
- Turning $CO_2$ into rock: feasibility 7, cost moderate, risk 3. Since the *Popular Science* article in 2005, the CarbFix experiment has started at Hellisheidi, Iceland, fixing $CO_2$ in basalt using that nation's abundant geothermal power. The limitation is that the feedstock and $CO_2$ must be heated to high temperatures.[131]
- Wind scrubbers to filter carbon dioxide from the air: feasibility 4, cost high, risk 4 – the Royal Society report (Shepherd et al. 2009) might rate it even lower. Giant porous filters would act like flypaper, trapping $CO_2$ molecules to be bound with sodium hydroxide or calcium hydroxide-chemicals that would be pumped through the filters. The $CO_2$ would then be stripped from the binding chemical, and sequestered.
- "Fertilization" of oceans with iron to encourage growth of plankton, again given the thumbs down by Shepherd et al. (2009), especially on risk: Feasibility 10 (pilot project already carried out, with spectacular impact on plankton growth), cost low, risk 9. The risk is very high because the resulting plankton blooms, in addition to gorging on $CO_2$, may devour other nutrients. Deep currents carry nutrient-rich water from the Southern Ocean northward to regions where fish rely on the nutrients to survive.

  The Royal Society report also mentions other "fertilization" techniques, such as increasing the phosphorus and nitrogen content of the oceans, but again the risk is seen as high (Shepherd et al. 2009, p. 18).

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[130] Canada joined in 2007 as a seventh member. The organization is still formally in place.

[131] The project participants comment (http://www.or.is/English/Projects/CarbFix/AbouttheProject/): "It shall be kept in mind that the amount of pores in the basaltic rock is limited. Therefore, the results from the Hellisheidi experiment will not save the world's climate. However, the experiment might demonstrate that a "near zero $CO_2$ emission" geothermal power plant is a possibility and even the option to store the main part of Iceland's $CO_2$ emission in a safe way. This technology, if proved successful, can then be exported to other basaltic terrains of the Earth." In the absence of geothermal sources, however, the technology is less likely to result in a net reduction of atmospheric $CO_2$, using fossil fuel in the heating process.

The recent UNEP report on *Blue Carbon* (binding carbon in the oceans) comes to similar conclusions (Nellemann et al. 2009). "With too many unknown variables and current modeling limitations, assessment of the risks and consequences of these proposals will be a challenge. .. Current research shows that most ocean geo-engineering concepts are high risk for undesirable side-effects (e.g. increase in ocean acidification), have limited application, uncertain outcome and potentially non-reversible impacts on the marine environment. This highlights the need to apply a precautionary approach when investigating ocean geo-engineering interventions." (p 41)

- Improving the ability of clouds to reflect sunlight back into space: feasibility 6, cost moderate, risk 7. The proposal is to seed clouds with tiny salt particles to enable more droplets to form – making the clouds whiter and therefore more reflective. The high risk assessment reflects concern that although the tiny salt particles released by evaporating sea mist are perfect for marine stratocumulus-cloud formation, they are too small to create rain clouds. It might make it harder for rain to form.

- Deflection of sunlight from the Earth through the use of a giant space mirror "spanning 600,000 square miles": feasibility rated extremely low at 1, cost extremely high, risk 5. In 1989, James Early of the Lawrence Livermore National Laboratory proposed deflecting a measure of sunlight with a "space shade" located at Lagrangian Point *L1* – an orbit 1.5 million kilometers up, where Earth's gravity and that of the Sun are balanced so an object can remain stationary relative to both bodies. The low rating on feasibility and the high cost suggest that this option is doomed in the foreseeable future. It would weigh about 100 megatons under Earth's gravity. As for assembling his giant mirror and placing it at L1, Early suggested using moon rock for the materials and building a manufacturing plant on the lunar surface, then launching the components by a mass driver from the Moon to L1 (Williams 2007).[132]

Looking at the six options listed above, there would seem to be little chance for any of them to become worldwide solutions in this century. The first two are not really geoengineering options in the sense that they represent even potentially large-scale manipulations of the global environment, but they could have some limited applications in suitable positions as the leaders of the Icelandic project suggest.

The four other options fall squarely in the area of geoengineering, options relying on "big fixes". They carry heavy environmental risks (especially the plankton option), or are

[132] Roger Angel, University of Arizona Professor and the Steward Observatory Mirror Laboratory's director, has offered another plan: to place in orbit at L1 a very great number of small, already assembled objects. Angel's plan calls for small "flyers": transparent sheets two feet in diameter and 1/5,000 of an inch thick, each weighing approximately one gram under Earth's gravity. Trillions of these objects, according to Angel, could together form a cylindrical cloud having a diameter half that of Earth's and a length of 60,000 miles. Interposed lengthwise between the Sun and Earth at L1, this cloud would uniformly reduce sunlight on our planet's surface by 2%, which would be sufficient to offset the warming produced by even a doubling of atmospheric carbon dioxide. Angel estimates that the total mass of all the flyers composing his cloud would be 20 million tons and a total of 20 electromagnetic launchers. At $10,000 a pound, conventional rockets would be a prohibitively expensive way of getting that much mass into orbit. Human beings would have to launch a stack of flyers every five minutes for 10 years to put the whole structure in place. Angel stresses that his plan is an emergency option, for use only if climate change so accelerates that global catastrophe looms within a decade or two. It is, he says, "no substitute for developing renewable energy, the only permanent solution." (Williams 2007 ).

prohibitively expensive and in a 21st century context technically impossible in view of the size and weight of the mirror and how and where it would be placed at L1. The last option to be discussed, however, is a geoengineering idea which has gained prominence under the influence of a distinguished main supporter, after three decades of theoretical debate.

***Particles into the Stratosphere***

Stephen Schneider (1996) relates how the geoengineering concept by the mid-1990s was maturing from a somewhat wild past: "Schemes to modify large-scale environment systems or to control climate have been seriously proposed for over 50 years, some to (1) increase temperatures in high latitudes [*sic*], (2) increase precipitation, (3) decrease sea-ice [*sic*], (4) create irrigation opportunities or to offset potential global warming by spreading dust in the stratosphere to reflect away an equivalent amount of solar energy." (p 291).

The last item is what concerns us here. The originator of the idea was Russian climatologist Mikhail Bodyko (1977), proposing a stratospheric particle layer to reflect away enough sunlight to offset greenhouse warming (Schneider 1996, p 293).

The National Academy of Sciences brought it into the debate in a 1992 report on the policy implications of climate change. Stephen Schneider, as a panelist, "reluctantly" voted in favor of retaining the chapter on geoengineering in the report, which centered on the stratospheric option. The majority of panelists felt that humanity is already involved in a large project of inadvertent "geoengineering" by altering atmospheric chemistry, and that engineered countermeasures need to be evaluated but should not be implemented without broad understanding of the direct effects and the potential side effects, ethical issues, and risks (Schneider 1996, p 296).

Edward Teller, the nuclear physicist famously linked to the hydrogen bomb, supported the idea despite being doubtful that climate change even existed. "It's wonderful to think that the world is so very wealthy that a single nation – America – can consider spending $100 billion a year on a problem that may not exist." "Let us play to our uniquely American strengths in innovation and technology, offsetting any global warming by the least costly means possible." "Injecting sunlight-scattering particles into the stratosphere appears to be a promising approach. Why not do that?" (Teller 1998)

Nobel Prize-winning Dutch chemist Paul Crutzen brought the idea to the fore. In an editorial essay in the journal *Climatic Change* (2006) he noted that $CO_2$ emissions from fossil fuel burning is partly offset by the cooling effect of sulfur dioxide particles, but at a high price because the pollution particles affect health and lead to more than 500,000 premature deaths per year worldwide. Furthermore, global $SO_2$ emissions and thus sulfate loading have been declining at the rate of 2.7% per year, potentially explaining the observed reverse from dimming to brightening in surface solar radiation noted in Appendix 3.[133]

[133] Sulfur is not the only proposed material. Gregory Benford suggests that the particles could be composed of diatomaceous earth. "That's silicon dioxide, which is chemically inert, cheap as earth, and readily crushable to the size we want," he says according to Williams (2007). Williams also quotes Stanford University climate scientist Ken Caldeira: "It appears as if any small particle would do the trick in the necessary quantities. I've done a number of computer simulations of what the climate response would be of reflecting sunlight, and all of them

Crutzen noted that his idea is not new, but no one had previously linked climate cooling and improved health. Among possible negative side effects, the impact on stratospheric ozone came to his mind first. However, he found that the impact on the ozone layer would be minor compared with major volcanic eruptions like that of Mount Pinatubo in the Philippines in 1991.[134]

The Royal Society report (Shepherd et al. 2009, p xiii) noted: "Of the Solar Radiation Management methods considered, stratospheric aerosols are currently the most promising because their effects would be more uniformly distributed than for localized Solar Radiation Management methods, they could be much more readily implemented than space-based methods, and would take effect rapidly (within a year or two of deployment)."

There may, however, "be serious consequences should geoengineering fail or be stopped abruptly. Such a scenario could lead to very rapid climate change, with warming rates up to 20 times greater than present-day rates. This warming rebound would be larger and more sustained should climate sensitivity prove to be higher than expected. Thus, employing geoengineering schemes with continued carbon emissions could lead to severe risks for the global climate system." (Matthews and Caldeira 2007, p 9949). Shepherd et al. (2009, p 24) note that "it cannot be foreseen whether or not such a rapid cessation might ever occur, or under what circumstances." In any case, the Royal Society report favors mitigation over any radical geoengineering solution.

### ***Geoengineering as a political crutch***

Australian academic Clive Hamilton's latest book is deeply pessimistic, so much so that he calls it *Requiem for a Species* (Hamilton 2010). It starts from similar ground as our appendices, especially 3 and 4, but it has chapters on "growth fetishism," consumerism, "many forms of denial" and "disconnection from nature," which springs naturally from the author's specialty of public ethics. While the main purpose for the Florida Keys project has been to provide perspective for the four scenario stories (assuming they remain equally plausible), Hamilton concludes that "it is too late to prevent far-reaching changes in the Earth's climate", and "those who want to argue that I am too pessimistic must explain where the analysis goes wrong." (p xiii) The general view, judging from the literature, is that the situation is serious but there is still room for a reversal, given appropriate action. Hamilton is right, however, in stressing the severity of the situation, and his book should be read widely.

Hamilton calls his Chapter 6 "Is there a way out?" (pp 159 ff). He points to three technologies that might seem to offer hope: carbon capture and storage (already discussed in an earlier section including Hamilton's comments), renewables and nuclear power, and geoengineering. On CCS, he endorses *The Economist*, writing on March 5, 2009 on 'The

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indicate that it would work quite well. I wouldn't look to these geoengineering schemes as part of normal policy response, but if bad things start to happen quickly, then people will demand something be done quickly."

[134] Also, as noted by NASA and others, the Antarctic ozone hole was healing following the international regulation of chlorofluorocarbon (CFC) gases through the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (http://ozonewatch.gsfc.nasa.gov/facts/hole.html). This was coupled with complex other factors related to aerosols indicating multitudinous feedbacks leading to the conclusion of one research team that the scientific understanding of climate and other drivers, interactions, and impacts remains very low. This includes a probable positive relationship between ozone hole healing and a warming climate (Carslaw et al. 2010).

illusion of clean coal': "CCS is not just a potential waste of money. It might also create a false sense of security about climate change, while depriving potentially cheaper methods of cutting emissions of cash and attention – all for the sake of placating the coal lobby."

Basically dismissing a revival of nuclear power as too slow to implement (he is not against it in principle), he notes under the heading of "wind, sun and atom" (p 173): "An emergency response over the decade to 2020 based on a huge effort to shift from fossil fuels to energy efficiency, renewable energy and natural gas is certainly feasible technically. It could also be achieved at reasonable economic cost. This is not to say it would be painless. .. Sadly, the national and international political institutions that must bring about the changes are too slow, too compromised and too dominated by old thinking to mandate the energy revolution we must have to guarantee our survival."

This leaves geoengineering or "climate engineering" as a potentially dangerous crutch. Hamilton puts is as follows (pp 185-186): "Fossil fuel corporations are currently unwilling to support geoengineering in public for fear of being accused of shirking their responsibilities, but once the approach becomes part of the mainstream debate and gains political traction we can expect to see the commitment to cut greenhouse gases diluted. The promise of geoengineering is the perfect excuse for decades of delay. If, as the Stern report says, climate change is the biggest market failure we have ever faced, geoengineering is the most serious *moral hazard* we have ever faced." (Our emphasis)

The reference to "moral hazard" is important and needs explanation. The Royal Society report on geoengineering (Shepherd et al. 2009, p 37) states: "The very discussion of geoengineering is controversial in some quarters because of a concern that it may weaken conventional mitigation efforts, or be seen as a 'get out of jail free' card by policy makers. .. This is referred to as the 'moral hazard' argument, a term derived from insurance, and arises where a newly-insured party is more inclined to undertake risky behavior than previously because compensation is available. In the context of geoengineering, the risk is that major efforts in geoengineering may lead to a reduction of effort in mitigation and/or adaptation because of a premature conviction that geoengineering has provided 'insurance' against climate change."

The Royal Society clearly prefers mitigation to geoengineering, for reasons both of justice and the moral hazard argument against it (p 39). But the authors conclude that the moral hazard argument requires further investigation to establish how important an issue this should be for decision-makers (p 45). As his reference to geoengineering as an unprecedented moral hazard shows, Hamilton is concerned that this inconclusive finding may encourage vested interests to push it at the expense of other climate control measures.

In conclusion, Hamilton reinforces our own strong impression that these radical technologies should not be given priority over the other approaches discussed in this appendix. The way to combat climate change is not to manipulate nature but to realize that human systems must be subordinated within the possible to avoid wrecking the natural environment any more than has happened to date. The vast majority of climate scientists agree on this. So does Graeme Taylor in *Evolution's Edge* (2008) with the requirement that "the paradigm must be flipped" to fit economics and business within the capacity of the natural environment rather than the other way round which currently prevails (Appendix 3).

### *Geoengineering and the four scenarios*

A common feature among those debating large-scale geoengineering options, including Crutzen (2006), the scientists quoted by Williams (2007), and Shepherd et al. (2009), is that they all regard these technologies as possible fallback options, and would much rather see greenhouse gas emissions reduced through conversion to renewable fuels, better energy efficiency, and reforestation. But they have generally taken a pessimistic view of the political and economic will to take action. Gregory Benford of the University of California put it bluntly (as quoted by Williams 2007):

"The political impossibility of what I call the prohibitionist agenda – that is, carbon prohibitionism – brings a kind of hallucinogenic quality to the global-warming discussion. No economist I know believes that global carbon emissions can be restrained within a century to even the level we have now. Every economist knows that the timescale for changing energy infrastructure is at least half a century to a century, just because of replacement costs. Economists are scientists too, and ignoring them isn't just blind: it's perverse."

This may explain why he and others have become proponents of large-scale geoengineering fallback options, but it reveals either ignorance or rejection of the emerging discipline of climate change economics, and the rising impact of Chinese green technologies which could have a profound influence on future climate change agreements (see further Appendix 5).

As far as the scenarios are concerned, it was stated in the introduction to this section that geoengineering may be attempted some time in future, but mitigation including such attempts is not part of the basic storylines. The scenarios are to be allowed to run their course to demonstrate the consequences.

## ENERGY EFFICIENCY MEASURES

*Ten technologies to save the planet* (Goodall 2008) noted only one technology (or domain of technologies) making the list under the heading of energy efficiency: "super-efficient homes", epitomized by the "Passivhaus" (passive house), four townhouses built in Darmstadt, Germany in 1990-91. Another of Goodall's ten technologies, distance heating, was linked to fuel cells but really represents another way to use energy more efficiently. The last heading in this section shows a small selection of the numerous other ways that exist to improve energy efficiency. Building applications have proven most spectacular, but the mass of individual energy efficiency applications adds to a potentially huge total contribution.

### *The passive house*

The idea germinated from a conversation in May 1988 between Professors Bo Adamson of Lund University, Sweden, and Wolfgang Feist of the Institute for Housing and the Environment in Darmstadt.[135] Thanks to efficient insulation and clever design, the houses did not need a conventional central heating system, nor would they need air-conditioners for the summer. Goodall lists the key features: architectural design and construction, passive solar design, super-insulation, advanced window technology, airtightness, mechanical

[135] Wikipedia (Passive House, as at October 2009). The institute is owned by the State of Hessen and the City of Darmstadt.

ventilation systems with heat recovery, and recovering the waste heat from lighting, appliances, and human and animal bodies. He notes (p 119):

"Heating and cooling don't get quite the same media attention in the climate-change debate as cars and electricity-hungry gadgets. But they should. If you added up the emissions of all the world's gas and oil boilers, coal fires, electric heaters and air-conditioning units, then you'd probably find that managing the temperature of buildings – either through heating or air-conditioning – is the world's single most climate-damaging activity."

There are now an estimated 15-20,000 passive houses in the world, mainly in Germany and Scandinavia. The first passive house in North America was built in Urbana, Illinois, in 2003 to demonstrate that the stringent passive house energy standards could be met in the severe climate of Central Illinois, as much as in Scandinavia .[136]

Goodall (2008, p 142) concluded that the technologies for improving the energy consumption of domestic housing are simple and relatively well understood, to a large extent because of the work of Wolfgang Feist and the Darmstadt institute. Insulation and airtightness are key factors. So far, however, developed countries have been slow to see the potential.

***Distance heating***

District heating was developed many decades ago to offer households a relatively cheap way of obtaining heat in winter, long before climate change became an issue. The first modern systems were built in the US the 1880s and in Europe in a number of German cities in the 1920s (Ericsson 2009). In Denmark, the first local district heating associations also go back to the 1920s.[137] Today, 60% of Danish households benefit from district heating, of which 75% comes from central and regional power stations.[138] Other European countries with a high proportion of residential and non-industrial premises served by district heating include Iceland (95%, using the abundant geothermal energy available there), Estonia (52%), Poland (52%), Sweden[139] (50%), Finland (49%), and Slovakia (40%). These high rates contrast with Germany (12%), the Netherlands (3%), and the United Kingdom (1%). [140]

[136] The designer was German-born Katrin Klingenberg, who applied several of the many techniques, systems and materials that can be used to reduce energy load by the required 90%. Among them: super-insulation and a super-tight thermal envelope, orientation that maximizes passive solar heating in winter and cooling in summer, triple-glazed windows, a 100-foot long earth-tube air intake for pre-heating and –cooling, heat recovery ventilation that recovers heat from exhaust air and ensures constant outdoor air ventilation for excellent indoor air quality, and instantaneous electric water heating. (http://www.e-colab.org/ecolab/SmithHouse.html).

[137] http://www.danskfjernvarme.dk/

[138] http://www.danskenergi.dk/EnergiITal/Elforsyning.aspx.

[139] Sweden provides a good example of the important role district heating systems can play an in increasing the use of renewable fuel sources for heating purposes, as well as reducing total primary energy demand (Ericsson 2009). The economies of scale of district heating systems provide an opportunity of using deep geothermal heat as well as unrefined biomass such as waste wood, straw, and forestry residues, and municipal solid waste. The Swedish example also shows how quickly the feedstock composition can change.

Until 1980 Swedish distance heating relied almost completely on oil. In the 1980s oil was replaced by solid fuels including biomass, peat, municipal solid waste, and especially coal. Electric boilers and large geothermal heat pumps also began to be installed in this period. In 1985 natural gas was introduced in Sweden and entered distance heating production. In the 1990s many of the coal-fired plants were converted to biomass which

District heat and power schemes supply entire urban areas, as distinct from fuel cells which may be scaled up to power and heat large buildings. A centrally located heating plant, often fueled by local wood, provides the heat for the surrounding households. Increasingly, however, district heating plants are being used to generate electricity as well as heat, as has long been the case in Denmark. Most Danish plants are still powered by gas and other fossil fuels, but about 40% of the heat produced is $CO_2$-neutral, because the plant has burned renewable wood or domestic waste. However, substantial issues remain because there are other ways of using organic materials, notably to produce either cellulosic ethanol or biochar (Goodall 2008, pp 113-118).

***Other energy efficiency ideas***

Despite Goodall's rejection of other energy efficiency measures in his list of ten technologies, there are numerous opportunities, and his remark (p 271) on the limited impact of energy-efficient home appliances overlooks the value of promoting and marketing these efficiencies – constantly making people conscious of the importance of energy efficiency across a wide range of products and services.

One well-known book from the 1990s is *Factor Four* (Weizsäcker et al. 1997) by the founder and former president of the Wuppertal Institute for Climate, Environment and Energy in Germany, Ernst von Weizsäcker, and resource analysts Hunter and Amory Lovins who founded the Rocky Mountains Institute in Snowmass, Colorado in 1982. The book sets out to demonstrate that resource productivity can grow fourfold; we can live twice as well, yet use only half as much.

Part One gives "fifty examples of quadrupling resource productivity" through energy, material, and transport productivity. They demonstrate the potential and scope for applying energy efficiency measures:

- Building design: The Darmstadt "Passivhaus"; space-cooling in hot-climate houses in California; super-windows and large-office retrofits; renovating old housing stock using super-insulating finishing material.
- Exploiting a huge potential for improving air-conditioning technology in six simple steps: keeping unwanted heat out of the building; expanding the "comfort envelope" using office chairs with mesh seats that ventilate the body, super-windows, ceiling fans etc.; passive cooling removing unwanted heat through the normal functioning of the building itself, without special equipment; cooling alternatives to air-conditioning; improvements to conventional air-conditioning; better controls and software for other energy use.

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expanded considerably and has continued to do so ever since. Apart from the biomass expansion in the 2000s the use of municipal solid waste has been greatly increased, and electric boilers have been nearly phased out.

The biomass use consists mainly of wood fuels (44% of the total energy supply in 2007), such as forestry residues and waste products such as demolition wood and loading pallets, and wood pellets. The remaining biomass is mainly tall oil, a by-product of pulp production. The biomass has for the past 10-15 years included both imported fuels as a result of the high biomass demand in Sweden compared to that in other countries. The biomass imports include wood fuels from the Baltic countries, wood pellets from Canada, and waste wood and other waste from Germany and the Netherlands. The imports from Canada have been criticized as running counter to the principle of minimizing the environmental footprint through distance heating.

[140] Wikipedia: District heating, accessed October 2009.

- Appliances and office equipment: More efficient refrigerators, refrigerator-freezers, washing machines, dishwashers, clothes dryers, electric cooking equipment, heat pumping, and ventilation; incandescent lamps, tubular fluorescent lamps, and lighting design; computers moving to laptop size; design synergies including power supply; more efficient printers, fax machines and photocopiers; reducing the number of solar panels drastically by converting from AC to DC; using low-voltage DC for other domestic use.
- Better application of engineering principles: Applying common sense, whole-system engineering, healthy skepticism about traditional practice and rigorous application of accepted engineering principles.
- Achieving better energy efficiency of power generation: More efficient new-generation power stations using combined-cycle gas turbines; adding combined heat and power and optimized gas boilers.
- Better material productivity based on material inputs per service unit (MIPS) or "embedded energy" taking account of all the energy going into a product from raw material through distribution to consumers to the final disposal of discarded units; reducing MIPS through durability and availability of replacement parts; new technology like electronic books and catalogues; steel versus concrete, favoring steel for applications like high-voltage transmission, pylons and bridges; water efficiency in a wide range of manufacturing processes; residential water efficiency; reducing waste in industry; reducing production of toxic chlorinated solvents through recovery and reuse; using less concrete for stabilizing walls; recycling wrapping plastic and reusing bottles, cans and large containers.
- Transportation-related efficiencies: videoconferences; electronic mail; reducing the transport intensity of consumer goods ("local blackcurrant juice versus overseas orange juice", in the German context); public transport options like multiplying the capacity of existing railways and introducing resource-efficient new-technology fast trains; more fuel-efficient cars; lighter cars; car sharing and car renting; developing "urban villages" with co-located job opportunities, encouraging home-based businesses, and reducing local travel to walking and bicycling. (Expanding local rail networks in major cities come to mind too, in situations where people still have to commute across cities to work. )

More than a decade has passed since *Factor Four*, and the list would be different if compiled today. While undoubtedly missing some details, it does provide the most complete review we were able to find – with the qualification that these technologies are all material. As Brian Arthur showed (Arthur 2009a), not only will design efficiency depend on the hierarchy of building blocks that are themselves technologies falling into place, but it also depends on the continued evolution of non-material technologies such as organizational design and knowledge systems.

### LAND MANAGEMENT TECHNOLOGIES AND FOOD SECURITY

These technologies are concerned with the 45% of all carbon captured by photosynthetic activity on land, and other forms of sequestering carbon through natural processes. Most current technologies using natural processes to capture atmospheric carbon dioxide, or preventing greenhouse gases from escaping into the atmosphere, are land-based. It is recognized, however, that the oceans form the largest carbon sink accounting for the remaining 55% of photosynthetic activity (Nellemann et al. 2009). "Blue carbon", as the oceanic sink has been called, is considered in the next main section.

Before going more deeply into technologies that are directed towards reducing greenhouse gases, it is recognized that one of the world's top concerns over the coming forty years will be food security – how to meet demand from a world population one-third larger than today's, generating demand perhaps 70-80% higher. The new technologies have to coexist with this, and if possible help secure adequate food supplies across the planet. There will be formidable conflicting objectives as in the case of fighting climate change itself.

A *New Scientist* article (MacKenzie 2009) assesses four key ways to boost food production to "feed the 9 billion" – hold on to water, stop plowing, go back to basics, and boost yields. Focusing on developing countries, including Africa, holding on to water lost through evaporation or run-off, drip irrigation, no-till farming, better use of fertilizers and pesticides, and improving transport and storage systems which are currently preventing farmers from connecting effectively to markets, are energy efficient technologies. Some are "simply" about providing better roads for the produce to reach their market, reducing the great waste from poor distribution systems, and taking advantage of better communication facilities like the spread of cell phones for access to price information and other market data.

The fourth alternative, to boost yields through genetic engineering of wheat, corn, and rice, as recommended by organizations such as the International Food Policy Research Institute (IFPRI), would need to be balanced against the risk of perpetuating, or returning to, monoculture. The section on biotechnology below depicts an area of great technical potential with political and ethical implications that continue to be debated on issues like genetically modified organisms and "big" versus "small" agriculture. Biotechnology, however, is part of our common future, where food security is becoming a crucial issue as populations and economies continue to grow.

Chris Goodall's (2008) top ten technologies include, as previously noted, two that fit under the heading of land-based technologies: *biochar* – sequestering carbon as charcoal, and *soil and forests* – improving the planet's terrestrial carbon sinks. Australian earth scientist and paleontologist Tim Flannery also thinks solving the climate problem is to a large extent associated with managing Earth's land resources. Like other scientists, he regards high-tech geoengineering methods of drawing carbon dioxide out of the atmosphere as "hypothetical" at best. The strongest prospect of large-scale draw-down of atmospheric $CO_2$ lies in changes to our agricultural and forestry practices, including the biochar technology described below (Flannery 2009, pp 68-99). Peter Cosier (2008), as already documented, considers land management fundamental to managing the atmospheric $CO_2$ balance.

Allan Savory, long-term campaigner for sustainable agriculture, advocates a two-path strategy to combat climate change (Savory 2008, p 5). The technologies described below offer a parallel route to the *high technology path* "based on mainstream reductionist science [which] is urgent and vital to the development of alternative energy sources to reduce or halt future emissions." The *low technology path* is "based on the emerging relationship science or holistic world view [which] is vital for resolving the problem of grassland biomass burning, desertification and the safe storage of [the] legacy load of heat-trapping gases that already exist in the atmosphere."

Sustainable farming, in which the natural resources such as soil, nutrients, and water are retained, are defined by the following criteria in Australia (Lehane 2001, p 2):

- Long-term real farm income: real and average real net farm income, total factor productivity, farmers' terms of trade, debt servicing ratio.
- Natural resource conditions: nutrient balance (phosphorus, potassium), acidity and sodicity,[141] rangeland condition and trends, species diversity of agricultural plants, water used by vegetation.
- Off-site environmental impact: chemical residues in products, salinity in streams, dust storm index, impact of agriculture on native vegetation.
- Managerial skills: level of formal education, participation in training and organized land care activities, implementation of sustainable practices.
- Socioeconomic impacts: age structure of agricultural workforce, access to key services.

The emphasis would differ from country to country, region to region, and according to level of development, but in the process of building up criteria this would provide a reasonable checklist to start with.

***Biochar***

Biochar is a fine-grained charcoal-like material produced by heating biomass under air-deprived conditions (pyrolysis). Feedstock includes residues from forests or crop production, manure, and green waste. Pyrolysis at relatively low temperatures of 300-600$^{O}$C changes the chemical properties of biomass carbon into structures that are much more resistant to microbial degradation than the original organic matter. Thus, materials that would rapidly release $CO_2$ and other greenhouse gases as they decompose, are transformed into a material that degrades much more slowly, thereby creating a long-term carbon sink. Biochar has mean residence times of several hundred to several thousand years in soils (Lehmann 2009).

Typically, about half the biomass undergoing pyrolysis is converted into biochar which can be returned to the soil. The rest becomes biofuels for transport and energy, or co-products (Figure 2). Nitrogen, ammonia and other nitrogen oxides, sulfur compounds, and carbon dioxide may be added to the biochar before returning it to the soil, to increase the carbon sink and nutrient contents (Krull 2009). Other useful additives include potassium and phosphorus (Goodall 2008, p 212).

Biochar differs depending on the feedstock; they may look alike but biochar from manure will have higher nutrient content than biochar made from woodchips, but the latter will be stable over a longer period of time. The heat treatment is also important. As an organic

[141] Problems associated with acidity include an increase of toxic minerals, a decrease in the availability of some plant nutrients and decreased microbial activity. Soil sodicity causes the swelling and dispersion of clay particles in the soil, which can result in hard-setting and water-logging. The consequence of this can be significantly reduced crop and pasture yields (Hajkowicz and Young 2005).

material, it is porous, but biochar produced at 700$^{O}$C has much higher adsorptive capacity (to bind particles to its surface), and is more porous than biochar produced at 400$^{O}$C. The higher heat makes it more capable of adsorbing toxic substances and rehabilitate contaminated environments (Krull 2009), and the porous structure helps retain nutrients and provides a structure that encourages the growth of valuable micro-fungi (Goodall 2008, p 212).

As a soil conditioner, biochar benefits soil quality in many ways including retention of nutrients, decreasing soil acidity, improving soil structure, and in the short term reducing the release of methane and nitrous oxide (Krull 2009).

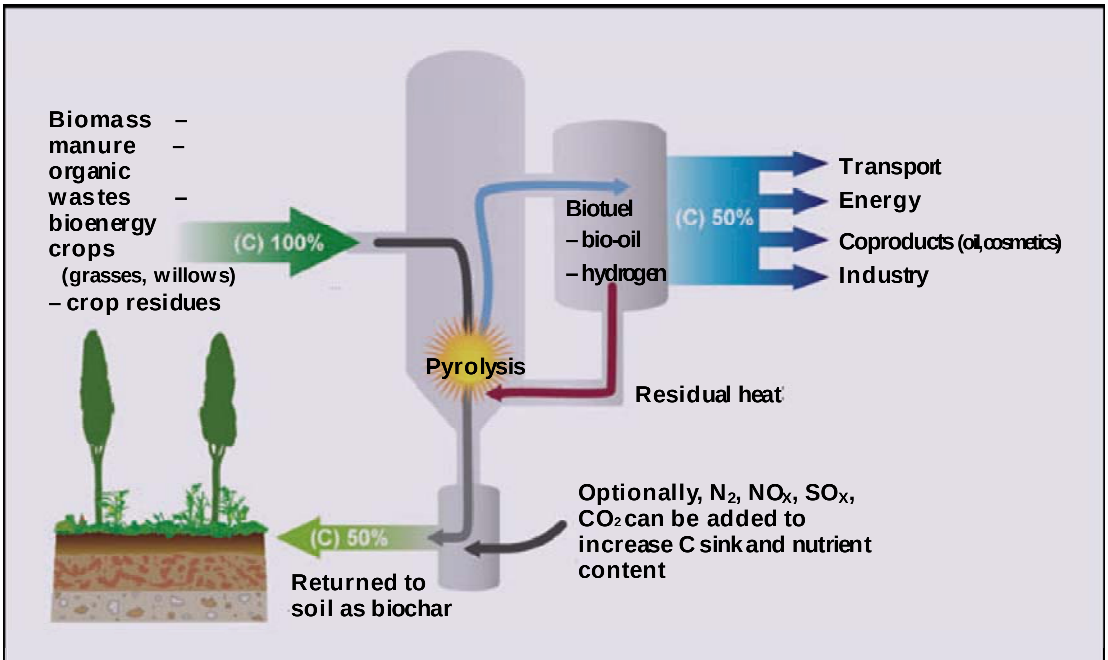


*Figure 2: Concept of low-temperature pyrolysis bio-energy with biochar sequestration. Typically, about 50% of the pyrolyzed biomass is converted into biochar and can be returned to soil.* Reproduced with the permission of the author and publishers from Lehmann (2007).

While charcoal burning is an ancient technology, and biochar is common in soil due to vegetation fires over thousands of years,[142] biochar is not yet being produced in great quantity. This may be associated with the cost of transporting the raw material to central processing units, which suggests that the technology may be most economically applied to decentralized positions. Lehmann (2007, p 384) contests this, however: “Several carbon costs are associated with the land-based production of biomass, transport to the bio-energy plant, pyrolysis itself, and land application of biochar (the latter is much less costly for biochar than for biomass, due to the fact that the mass per unit carbon of biochar is about 60% that of biomass). Our preliminary calculations take all of these carbon costs into account and suggest that the energy balance for various feedstocks, such as corn or switchgrass, is very favorable.”

[142] The *terra preta* soils in the Amazon (Portuguese for ‘dark earth’) are an outstanding example, which literally gave rise to the idea of adding charcoal to the world’s soils to reduce carbon dioxide levels (Goodall 2008, p 211).

The potential of biochar to help mitigate climate change is theoretical at this point, because there are few full-scale biochar systems. The technical potential of biochar to contribute one gigaton of carbon removals annually by 2050 (incidentally the size of a Pacala/Sokolow "wedge") will require carefully developed sustainability criteria, since the climate change mitigation value of biochar arises from several connected sources including energy and agriculture. "The potential for climate mitigation is highly variable from one biochar system to the next due to different feedstocks, scales, and applications, which requires careful evaluation. Biochar must be integrated into existing food production systems and not be an alternative to food production, make use of already developed best-management practices such as no-tillage or conservation agriculture, and, for efficiency, build on residue collection systems that are already in place." (Lehmann 2009, pp 4-5)

One potentially attractive feature of biochar technology, as discussed above, is that it may work successfully at different scales despite transport costs allegedly disadvantaging large-scale production. At the lower end of the scale, biochar can be made in tiny kilns that double as efficient cooking stoves, using locally available materials for fuel and giving householders some charcoal to feed the soil. Some – maybe a large part – of the world's deforestation is caused by families seeking wood for cooking (Goodall 2008, p 214).

At the higher end of the spectrum, a pilot plant has been built north of Sydney by the Australian subsidiary of US biomass technology company BEST Energies, Inc. (Madison, Wisconsin). In October 2008, this venture together with CSIRO Land and Water and the New South Wales Department of Primary Industries organized a meeting resulting in the formation of the Australian and New Zealand Biochar Researchers Network (ANZBRN) which aims to improve the coordination of biochar research and provide information about biochar and its benefits (Krull 2009). Evelyn Krull subsequently told the main Australian government broadcaster that three to five years' more research would be needed before Australian farmers could start using it.[143]

Another firm, EPRIDA, Inc. is based in Athens, Georgia. Its pilot plant processes chipped green biomass into syngas for power production, bio-oil, and biochar which is subsequently being organically enriched from a parallel waste-processing processing process (Day 2009).

Johannes Lehmann of Cornell University, leading expert on biochar technology, summarizes the environmental benefits under the following headings (Lehmann 2007, pp 384-386):

- Combating climate change causing a net withdrawal of $CO_2$ from the atmosphere.
- Improving soil by returning half the $CO_2$ to the land, and improving soil fertility from the biochar itself.
- Reducing pollution of waterways by retaining nutrients such as nitrogen and phosphorus[144] in the soil, and lowering the amount of groundwater leached into groundwater or eroded into surface waters.

[143] http://www.abc.net.au/science/articles/2009/03/04/2507238.htm.

[144] Another matter of potentially vital importance is that supplies of phosphate rock are dwindling; although experts disagree on how much is left and how quickly it will be exhausted, the deposits are a finite resource that

- Additional opportunities to reduce greenhouse gases by scrubbing air pollutants from flue gas (carbon dioxide, methane, nitrous oxide) .

Lehmann concludes (2007, p 386): "Bio-energy through pyrolysis in combination with biochar sequestration holds promise for obtaining energy and improving the environment in multiple ways. The technology has the potential to be carbon negative, which means that .. greenhouse gases would be removed from the atmosphere. This could be the beginning of a biochar revolution that is not only restricted to a bio-energy combination, but applicable to a range of different land-use systems. Compared to the limited amount of $CO_2$ that can be removed from the atmosphere by other land-based sequestration strategies, such as no tillage or afforestation, a biochar sink has the advantage of easy accountability and multiple other environmental benefits.

There are, however, possible pitfalls as well as gaps in our understanding of the science of biochar behavior in soil and how different pyrolysis conditions affect biochar ecology in the environment. Pyrolysis is currently being developed with the primary goal of maximizing the quantity and quality of the energy carrier, such as bio-oil or electricity. The optimization of biochar properties within a pyrolysis system has not been the focus of research to date, and biochar can have very different properties depending on the type of organic residue from which it is obtained and how it is produced. Certain production conditions and feedstock types can make the biochar completely ineffective in retaining nutrients and affecting atmospheric $CO_2$, or susceptible to microbial decay. Efforts similar to the development of fertilizers over the past century need to be undertaken to provide the underlying scientific information for biochar ecology that contributes to cleaner air and water while producing energy. The evidence overwhelmingly suggests that exploration and development of biochar bio-energy is highly promising."

In short, biochar technology is not yet ready to make a major contribution, but it shows promise, perhaps especially for its potential to increase agricultural productivity in the developing world.

***Tropical forests***

Tropical forests are particularly important because they grow steadily all year; they are also particularly efficient in keeping the planet cool through the transpiration of moisture and formation of clouds.

Tropical rainforests – and mangrove areas – have the highest terrestrial biodiversity in the world. They are disappearing at an alarming rate, and the negative factor of deforestation is one of the greatest sustainability issues, because it has potentially explosive effects, as when a tipping point may be approaching which will cause galloping destruction of the remaining Amazonian rainforest, beyond the direct damage caused by the steady logging that has taken place over the years. There is scientific consensus that the gradual loss of this rainforest will eventually not just affect greenhouse gas levels but will also change global

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could disappear within the century, maybe in decades. Cutting down on the use of phosphate-based fertilizers and improving their efficiency could be very important (Gilbert 2009).

weather patterns, probably making large areas of the western hemisphere much drier than at present (Goodall 2008, p 248).

The rainforests in Indonesia and Malaysia are still being replaced by palm oil plantations, of which a large part of the output goes into biodiesel vehicles in Europe. Other rainforest areas range from India and Burma in the west, while Bangladesh has the largest area of mangroves – but Central Africa and Madagascar have the second-largest tropical rainforest areas in the world, next to South America. Central America and northern Australia are other significant tropical rainforest areas, all under threat including their rich biodiversity.

Reforestation and afforestation, respectively denoting replacement of lost forested areas, and new plantings, are important but the effects are long-term while the removal of tropical forests is  a major short-term issue.

Deforestation in tropical areas may be partly due to large commercial farming interests wanting to expand production (like the Indonesian and Malaysian palm oil plantation operations). But Goodall (2008, p 249) points out that it also happens partly as a result of the decisions of millions of people trying to create new land on which to grow food. The effect of widespread woodland loss is to increase soil erosion and cut fertility.

The single most important change to cut these losses is probably to reduce the amount of wood cut down for cooking food. As in the discussion of biochar in developing countries, there are simple technologies that might help achieve this purpose. Fuel-efficient stoves are one possibility:

"About 2 billion people .. cook using wood or dung. We cannot really be sure of these figures, but some estimates suggest that each person needs about 800 kilograms of cooking fuel each year. Multiply the two numbers together and we get a global figure of about 1.6 gigatons of wood and dung used each year, of which about 800 million tons (50%) is carbon. UNEP says that forest loss produces about 1.1 gigatons of carbon a year, meaning that the cooking accounts for about three-quarters of the net loss of forest volume. Put another way, if we could cut the amount of wood fuel used in cooking stoves in half, this alone would reduce net man-made additions of carbon dioxide to the atmosphere by over 5%." (p 250)

These are remarkable numbers which might be accused of being glorified "back-of-the-envelope" estimates but do not seem to have been seriously criticized. Goodall goes on to suggest simple technologies such as fuel-efficient wood stoves, and solar cookers that focus the sun's rays on to a container of water (a minuscule version of the large-scale concentrated solar power technology described earlier).[145]

[145] A pioneering solar energy project in Misa Rumi, a village high in the Andes in northern Argentina, was sponsored by the NGO Fundacion EcoAndina (http://www.ecoandina.org/en/4706/4733.html). It is situated in an area known as La Puna, which was never connected to the electricity grid. The Argentine government installed solar panels there in the 1990s to provide lighting and power pumps for drinking water. Solar energy has helped keeping villages and towns alive and dissuaded families from moving into larger regional cities.

The project uses a variety of technologies for solar-fired stoves, solar-heated showers, heating a commercial bakery, water pumps for local vegetable growing, and heating the village school through black-roof panels to take the edge off chilly mornings. The president of EcoAndina, Silvia Rojo, said that the technology is improving quality of life and reducing firewood consumption which has caused desertification in the region. She added that the project has sparked a lot of interest in other Latin American countries like Colombia, Peru and Bolivia, and

“Another promising technology is the use of biogas collectors. When human, animal and plant waste rots down, they give off methane, particularly if kept in enclosed containers or left in a rubbish dump or landfill site. In most parts of the world, this methane vents to the open air but if it is collected it can be burnt in simple stoves, replacing the need for woody fuels.” (p 250)

The biogas technology also – and perhaps mainly, though again its potential in developing countries is an important consideration – lends itself to large-scale ventures, using farm waste including pig, cattle and chicken manure as feedstock in an anaerobic digestion process. This technology is widely used in Europe and is expected to gain further importance (Holm Nielsen and Oleskowicz-Popiel 2007). Piggeries are an important source but the plant needs to be large – based perhaps on 10,000 animals.

The original gas produced is about 50-75% methane and most of the remainder $CO_2$. To be fed into a gas grid it needs to be cooled, drained, and dried, cleaned for $H_2S$ (hydrogen sulfide), and subjected to separation from the $CO_2$ for upgrading to natural gas quality.

Undoubtedly the list of possible technologies could be lengthened. Some of those described here may apply particularly to tropical areas, but the wood-burning issue goes beyond these into the temperate areas of China and Central Asia. This also takes us into the last headings in this appendix, dealing with improved agricultural management.

The annual meeting on climate change in Bali in December 2007 (UNFCCC COP-13) focused on emissions from deforestation and degradation of tropical forests in developing countries. It proposed a new mechanism, Reducing Emissions from Deforestation and Degradation (REDD), for inclusion in the successor to the Kyoto Agreement. REDD is described and discussed in Chapter 4 of Esteban et al. (2008).

***Croplands***

Sustainable agricultural practices vary from country to country. It is a simple concept that embraces a complex web of issues: the state of the soil, water availability, choice of crop, stocking rates, needs for pesticides, herbicides and fertilizer, climate variability, and protection of biodiversity. Then there is a range of economic issues, such as markets and production costs. Developments in information technology will play a key role in managing the complexity. Any program to successfully develop a system of sustainable agriculture must have farmer involvement at all stages of its development, and must look at a farming system as a whole, not just at individual elements (Lehane 2001).

Lehane (2001)identifies four key issues for cropland management in Australia, a country used as an example only, given the differences that exist between nations:

- *Loss of biodiversity*: A productive soil is called a 'living' soil because of the enormous number and diversity of organisms that cycle nutrients through the soil, maintain its

worldwide, and that each of the solar technologies used in La Puna can be scaled up for larger communities (Stott 2009).

structure, and prevent outbreaks of pests and diseases. Above ground, many modern agricultural practices, including monocultures, poor crop rotation, pesticides and heavy machinery, reduce biodiversity to low levels and trigger even greater adverse responses, such as pesticide treadmills. Bio-fumigation presents one sustainable approach to suppressing soil-borne pests and diseases in crops, utilizing toxic compounds produced by brassicas (such as cabbages, turnips and mustard) to kill soil pathogens. Farmers can plant a brassica crop alternating with another crop to break the life cycle of soil pests and diseases, instead of using synthetic pesticides.

- *Dryland salinity* became more obvious when grasslands and savanna-type vegetation were replaced with crop and pasture plants. These annual crops take up less rainwater, so more water is added to the underlying water table. The water table then rises, bringing salt to the surface. What is needed for sustainability in these regions are farming systems that match the previous water use, thus halting the rise in the water table. One possible approach is 'agro-forestry' systems that combine tree growing with cropping and grazing. As with many environmental problems, there is not a single solution: options will vary enormously with local and weather conditions.
- *Acid soils*: The biggest losses in agricultural production come when acidity increases to the point where toxic elements in the soil, particularly aluminum, are dissolved. Adding lime is expensive on large areas. To promote sustainable management of affected areas, land-use approaches are being investigated that can slow or reverse the acid build-up, and working towards breeding crop and pasture varieties that grow well in acid soils.
- *Pests and weeds*: Integrated pest and weed management, based on a detailed understanding of the ecology and biology of the target organisms, is now seen as an important key to sustainable control. It can involve, for example, biological control, crop rotations, planting resistant or tolerant varieties, or using insect traps as well as sprays. Goals include keeping pesticide and herbicide use to a minimum and only using chemicals that are environmentally benign.

***Holistic livestock management and other agricultural techniques***

Allan Savory originated "holistic management", applied to cattle raising and developed since the 1960s, in his native Zimbabwe. It considers families, their economies, and the environment as inseparable, enabling people to make decisions that simultaneously consider economic, social, and environmental realities, short- and long-term. He notes (Savory 2008) that rangelands are similar to croplands – if the soil is bare any time of the year, they will deteriorate and release previously stored carbon. At the same time the ability of such rangelands to store water is reduced. Because much of the soil in rangeland areas is bare, erosion from them is even higher than for croplands.

Savory developed his ideas while working as a game ranger on the African savanna, where the grasslands support herds of millions of ruminants including wildebeest and other antelopes. He noticed that the vast African herds constantly moved across the landscape, heavily grazing an area, trampling the remaining dry matter into the ground, liberally fertilizing the soil with urine and manure, and then rapidly moving on. An Australian soil carbon specialist, John Lovell, has noted that the bison had similar habits roaming the prairies of North America (Goodall 2008, p 241).

Lovell has also focused on methane, a natural product in ruminants from the microbial fermentation in their digestive system and present in their manure, and how to eliminate this greenhouse gas problem through holistic management techniques (Lovell and Ward 2008). Methane can be made carbon-neutral or better according to Mark Adams of the University of Sydney's Faculty of Agriculture, Food and Natural Resources. In the high-plains country of New South Wales and Victoria, soil with high organic matter has been shown to oxidize more methane than the livestock can produce (slightly offset by bacteria producing $CO_2$ during the oxidization process). Adams sees another challenge in minimizing emissions of greenhouse gases from conventional broad-acre livestock operations (Cawood 2009).

The holistic management procedure for livestock mimics the movement and grazing patterns of the wild herds of old (except that the result is achieved through fencing), minimizing overgrazing of plants while harnessing the beneficial soil-preparation effects of trampling hooves that knock down old vegetation, chip bare soil surfaces, and cover them with manure.[146] The resulting increase in vegetation gradually fills in bare spaces, keeping the soil covered year round, and once again storing both carbon and water, and helping to ensure food and water security.

According to Savory (2008), the dry rangelands alone are estimated to constitute over 4.9 billion hectares worldwide, and the medium to higher rainfall grasslands increase the area significantly. He claims an estimated 12 million hectares is currently managed holistically across Australia, Africa, Mexico, Canada and the United States, and that increasing soil organic matter by a modest 1% on 12 million hectares (120,000 $km^2$) would remove 3.6 gigatons of $CO_2$-equivalent greenhouse gases, as well as helping to reverse desertification of the world's rangelands.

Allan Savory's concept of holistic management of livestock is also known under names such as "cell-grazing" or "block-grazing". It has been applied to sheep, poultry, goats, and other animals as well as cattle. In Australia, to take an example, cell-grazing operations are found from Tasmania in the south, to extensive rangeland ventures in the north of the continent. Operations can range in size from, say, 60 head of cattle or less, to 3,000 or more.

It is also a growing activity in the highland country west of Sydney, Australia, where the author lives. The person who started the first cell grazing operation in the district in 1996 lists the following features of his relatively small operation – all features that apply to cell grazing whether at large or small scale: [147]

- There are nine enclosures, in which the cattle successively eats the grass down, until one to two days' feed remains, when they are moved to the next enclosure. The remaining grass is left as mulch for new growth, which is fertilized by the dung left behind.

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[146] This argument in favor of hoofed livestock, within carefully managed enclosed systems, contrasts with the erosion and run-off problems met in conventional broad-acre operations.

[147] John Martin, cell grazer in Oberon, Australia, personal communication. Now in his seventies, he recently sold the property described and is now running a smaller, eight-hectare four-cell operation breeding goats. This illustrates, once again, the flexibility of cell-grazing from large to small, and the suitability of different animals.

- In this operation, the animals were weaned at eight months and marketed the month after, when reaching about 300 kg. No artificial feed or growth hormones were used. Various techniques ensured that cows and calves enjoyed stress-free conditions during the weaning process.
- Cell grazing is flexible, fitting a wide range of climatic and soil conditions. The cycle of returning to the first enclosure varies from as little as two months in areas with good rainfall. In large holdings, the livestock may be moved every 24 hours.
- To maintain sustainability, stock numbers are limited to match the weight of organisms fertilizing the underlying soil (most of the weight of grass is underground, where it benefits from the carbon-rich nutrition).
- Carbon is returned to the soil and not to the atmosphere, through rotting plant matter.
- It is easier to control internal parasites of cattle because the rotation from cell to cell in the grazing system breaks the natural cycle enabling the parasites to take hold. Poultry may be used initially to eat local parasites before sending in the cattle.
- Biodiversity is enriched through a multiplicity of different grasses that were previously not able to develop. Because different grasses contain different nutrients, the livestock diet is better balanced.
- The enriched biodiversity builds up year after year – when there has been a need to rip up existing cells in the system, they have taken 10 years to recover.
- Cell grazing is more economical on fertilizer, which is released slowly from the ground as required.
- Cell grazing encourages a smaller and more efficient composition of the agricultural workforce because it requires little or no machinery. If any is required, contractors are used. Small cell-grazing properties like the one described are virtually one-person operations.
- The need for haymaking to provide extra feed is eliminated in this type of self-sustaining system.

Other advantages could be enumerated. Qualitative research into cell-grazing in Queensland's rangelands finds that it is "an emerging ideology of pastoral ecology." (Richards and Lawrence 2009) It has been described in terms of three foundations: family support, soil health, and animal health. Women have been observed to be relatively actively involved, whereas conventional grazing operations tend to be male-dominated .

Richards and Lawrence (2009) conclude (p 638): "Although cell grazing does not currently offer a significant challenge to conventional grazing and its associated environmental problems, it does offer the possibility that an alternative form of production is able to operate in a manner that is both economically viable and environmentally sustainable. Cell graziers have exhibited the ability to adapt to both market and climatic conditions by reconfiguring their own identities as producers, re-thinking cattle management techniques, embracing a new, more entrepreneurial business philosophy, and focusing upon the condition of the environment."

Other agricultural techniques are also important, such as zero-tillage to keep the carbon in the soil rather than exposing it through plowing, which degrades the complex molecules in the humus which preserve soil structure and provide nutrients for plants, into carbon dioxide, methane and other simple structures. Generally speaking, soils with high levels of complex molecules are best for the climate and agricultural productivity. In summary, the techniques mentioned in this section "are the simplest and most basic of the portfolio of solutions to climate change, but they may also end up by being the most effective." (Goodall 1998, pp 252-253).

Importantly, these solutions lend themselves to small-scale applications in the developing as well as the developed world – many small enterprises combined can have a huge direct effect as carbon sinks, and by "spreading the word".

Back in the 1990s, the authors of *Factor Four* (Weizsäcker et al. 1997) offered other suggestions, which are undoubtedly just a few of many techniques that might be, or are being, adopted in our still highly diverse world:

- Increasing the energy efficiency in animal husbandry, where the input-output energy ratio varies between very low for free-range chickens living mostly on what they can find on the farm, and very high for *industrialized* beef production using animal feed from overseas. "Reducing export subsidies [in Europe] would save taxpayers huge amounts of money and radically reduce energy demand from the farms. .. It seems more than plausible that the energy "demand" from agriculture and food processing can be reduced by a factor of four with essentially no sacrifice of wellbeing." (p 51)
- Growing crops where the climate is suitable, as opposed to wasting energy on growing tomatoes in huge greenhouses as in the Netherlands (p 53).[148]
- Improving water-use efficiency in commercial irrigation schemes. In dry Arizona, it has been possible through subsurface drip irrigation to achieve 95% efficiency. The water savings were accompanied by other benefits like reduced tillage, replacing plowing and other operations, and increasing crop yields by 15-50% (p 80).
- Reinventing agriculture through perennial polyculture – possibly the most important idea on agricultural practices and one that sets out to reduce dependency on fossil fuels and the fertilizer industry, and biodiversity losses (pp 97-99). Wes Jackson[149] advocates in-depth exploration of how the never-plowed native prairie works as a basis for developing a diverse, perennial vegetative structure capable of producing desirable edible grains in abundance including perennializing the major grain crops. The key issues are: Can perennialism and increased seed yield go together at no trade-off cost to the plant? Can a polyculture of species out-yield a monoculture? Can perennial species planted in mixtures adequately manage all pests? Can a perennial polyculture sponsor

[148] This may clash with another of the 50 examples in Weizsäcker et al. (1997), encapsulated as "whether to drink local berry juice rather than imported orange juice" in order to minimize transport costs and use of fossil fuel.

[149] Wikipedia: 'Wes Jackson' (site accessed October 2009). Jackson is an American biologist and botanist with a Ph.D. in genetics who left academia in 1976 to found a non-profit institution, The Land Institute. He remains head of this institute, which describes its main goal as the development of Natural Systems Agriculture.

all of its own nitrogen fertility needs? "The implications and potential impact of this work are global." (Jackson 2002)

The work on perennial crops continues, especially in the United States. Stan Cox, Wes Jackson's colleague at the Land Institute in Salina, KS, in 2008 spoke on perennial cropping systems of the future at an agronomy conference in Adelaide, South Australia (Cox 2008). His message is summed up in this initial statement: "Agriculture's impact on the Earth has been amplified by industrial farming, but the fundamental problem has its origins 10,000 years ago, in the domestication of those annual crops that are still the staples of the global food supply. Annual crops, with ephemeral, often low-density root systems, have a lower capacity than do perennials to foster microbial ecosystems in the soil or micro-manage nutrients and water. .. Perennial grains, combined with established and novel sustainable-agriculture practices, could help end the 10,000-year-old conflict between food production and ecological health."

Cox (2008) explains: "The replacement of native perennial root systems with the annual roots of crops has subtracted or reduced many of the elements (e.g. carbon pools, micro-organism populations, and root channels) that make soils healthy. Annual crops also require frequent soil disturbance, precisely timed inputs and management, and favorable weather in critical, often narrow, time windows. In one field experiment encompassing 100 years of data collection, perennial crops were more than 50 times more effective than annual crops in maintaining topsoil."

He points out that there is a genetic cost involving in hybridizing perennials and annual crops, which have obviously acquired qualities that are essential for domestication. "Differences in chromosome number, lack of chromosome homology, and other factors can cause moderate to complete sterility and restrict genetic recombination in the progeny. The plant breeder working with such crosses must struggle with genomic disruptions while selecting to improve multiple traits simultaneously."

- Bio-intensive mini-farming. California-based Ecology Action since the 1970s has developed a system for highly productive and sustainable agriculture (Weizsäcker et al. 1997, pp 100-101). The system rests on four main principles: deep cultivation of the ground to provide for optimal root growth; production of compost crops to feed back to the soil; intensive spacing of plants in wide beds to create beneficial microclimates; and inter-planting of different plants to foil pests. The organization and its outreach has grown: the international network, as at 2009, covers most of Latin America and many other countries including Kenya, Zambia, Israel, Russia, Uzbekistan, Afghanistan, Nepal, India, New Zealand, and Micronesia. [150]

### *An Indian perspective on sustainable agriculture*

Vandana Shiva is a former leading Indian physicist (quantum theory) who became involved in interdisciplinary scientific research in science, technology, and environmental policy. In 1982, she founded the Research Foundation for Science, Technology and Ecology, which led

[150] http://www.growbiointensive.org/.

to the creation of Navdanya,[151] a biodiversity conservation program to support local farmers, rescue and conserve crops and plants that are being pushed to extinction and make them available through direct marketing. She is a prominent representative of new ways of dealing with sustainable agricultural production in developing countries.

She alleges that two myths keep the world poor (Shiva 2005). "First, the destruction of nature and of people's ability to look after themselves are blamed not on industrial growth and economic colonialism, but on poor people themselves. .. The second myth is an assumption that if you consume what you produce, you do not really produce, at least not economically speaking. If I grow my own food, and do not sell it, then it doesn't contribute to GDP, and therefore does not contribute towards "growth". .. Yet sustenance living, which the wealthy West perceives as poverty, does not necessarily mean a low quality of life."

While accusing rich countries of exploiting the developing world, for imposing western agricultural technologies including genetic engineering, and taking Jeffrey Sachs of the Millennium Project to task for "not understanding where poverty comes from", her Navdanya ("nine crops") program does represent an attempt to promote ecological agriculture based on biodiversity, for economic and food security. Navdanya pioneered seed saving, which began in response to the crisis of agricultural biodiversity, with the participation of the communities who have evolved and protected the plants and animals that form the basis of sustainable agriculture.

Navdanya is a gender-sensitive movement, led by women and putting women first. The gender program Diverse Women for Diversity seeks to strengthen women's grassroots movements and provide women with a common international platform to air their views.

Navdanya has worked with local communities and organizations serving more than two million farmers from all over India. It has established 34 seed banks in 13 states across the country "as it believes in operating through a network of community seed banks in different eco-zones of the country, and thus facilitating the rejuvenation of agricultural biodiversity, farmer's self-reliance in seed locally and nationally, and farmers' rights."

According to its website, Navdanya's efforts have resulted in the conservation of more than 2,000 rice varieties from all over India including indigenous rice varieties that have been adapted over centuries to meet different ecological demands, as well as conserving 31 varieties of wheat and hundreds of millets, pseudocereals[152], pulses, oilseeds, vegetables and multipurpose plant species including medicinal plants.

Again, the adoption of alternative technologies will differ between the four IPCC-based scenarios, which is the appropriate way of dealing with them.

### THE OCEANIC CARBON SINK

Oceans represent the largest long-term sink for carbon and also store and redistribute $CO_2$. The ocean's important vegetated habitats are in coastal areas: mangroves, salt marshes, and

[151] http://www.navdanya.org/.

[152] Cereals are grasses. Pseudocereals such as buckwheat and amaranth are grains, not grasses.

seagrasses.[153] They cover less than 0.5% of the sea bed but rank among the most intense carbon sinks on the planet, accounting for more than 50%, possibly over 70%, of all carbon stored in ocean sediments. Microscopic plants known as phytoplankton (measuring from 200 μm down to 0.2 μm)[154] also consume $CO_2$ through photosynthesis and are an essential part of the carbon cycle. While tiny, phytoplankton contribute significantly to the carbon budget of the planet due to be vast areas that they inhabit (more than 70% of the planet's surface). The sinking of phytoplankton such as coccolithophores from the surface layers of the ocean represents an important pathway for the sequestration of carbon into the depths. This sequestered carbon may remain stored there for millennia, as distinct from rainforests where the period depends on the lifespan of the trees.

Even though the plant biomass in the oceans is only 0.05% of all land-based vegetation, it cycles almost the same amount of carbon. But while increasing efforts are being made to slow down land degradation (as described in the previous section), the role of marine ecosystems has to date been substantially ignored.

The United Nations Environment Program (UNEP) in cooperation with other organizations has published a report called *Blue Carbon* to rectify the neglect of the oceans as carbon sinks (Nellemann et al. 2009). The term "green carbon" has been used mainly to describe the role of forests as natural sinks – though it should be capable of extension to other land management technologies. The term "blue carbon" has now been coined specifically to distinguish the role of the oceans from the role of forests and other green terrestrial areas.

The warming of the oceans that has occurred to date (0.64$^{o}$C over 50 years) has already caused a dramatic trend in the melting of sea-ice in the Arctic. Changes in temperature lead to an increase in the ocean volume through thermal expansion, and result in changes to the structure and circulation of the ocean. Rising temperature also drives more intense tropical storms. These changes add to the seasonal water-column stratification and coastal "flushing" mechanisms, resulting in more polluted coastal waters, algal blooms, and preventing food particles to reach organisms living in the deep sea and on the sea floor.

The ocean also acts as a buffer for the Earth's climate by storing and exchanging $CO_2$ with the atmosphere, and diffusing it towards deeper layers. However, this continual intake of $CO_2$ and heat is changing the ocean in ways that have potentially dangerous consequences for marine ecology and biodiversity, because dissolved $CO_2$ in sea water lowers the pH level, which is already causing significant acidification and a loss of chemicals such as carbonate ions, leading to changes in the biogeochemical composition of ocean waters. There is substantial evidence that calcification by corals and other organisms such as coccolithophores (phytoplankton) is decreasing as a result of these changes (Raven et al. 2005, Kleypas and Langdon 2006, De'ath et al. 2009, Doney et al. 2009).

The changes to the physical and chemical conditions in the ocean are now directly affecting the distribution of plankton, fish and other marine fauna and in the migratory routes of

[153] Mangroves and seagrasses are important in the Florida Keys. Salt marshes (tidal marshes) are common in Florida north of Cedar Bay and Daytona Beach but are replaced by mangroves further south (http://www.dep.state.fl.us/COASTAL/habitats/saltmarshes.htm).

[154] Micrometers or millionths of a meter.

many species. Last but not least in the context of this project, loss of coral reefs and associated biodiversity is listed specially as a major consequence of oceanic warming (Nellemann et al. 2009, pp 23-33).

From the technology angle, one reason the oceans have not been properly recognized in the context of climate change may be that they seem to lend themselves mainly to geoengineering proposals which are either in an early experimental stage or cause acidification (Nellemann et al. 2009, pp 42-43). Technology, however, is defined as means to fulfill a human purpose, which may not require a physical system but another "purposed system" (Arthur 2009a). In the context of this project such systems include marine sanctuary management, exemplified by the specialized organizations of the Florida Keys National Marine Sanctuary and Great Barrier Reef Marine Park Authority. Equally importantly, science itself, and the interface between science and technology, are purposed systems linking up with the marine sanctuary management organizations.

Vegetated coastal habitats – mangrove forests, salt marshes, and seagrass meadows – have been identified as by far the most important "blue carbon" sinks. They have much in common with rainforests, being biodiversity hotspots, providing essential ecosystem functions including their role as sinks, and experiencing rapid global decline. Vegetated coastal habitats rank amongst the most threatened ecosystems in the biosphere, with global loss rates 2 to 15 times faster than that of tropical forests, rapidly eroding the capacity of the biosphere to remove anthropogenic $CO_2$ emissions. Coastal eutrophication, reclamation, engineering and urbanization have led to the loss of a substantial fraction of the earth's blue carbon sinks since the 1940s (Nellemann et al. 2009, p. 45).

The main recommendations in *Blue Carbon* are, slightly abbreviated (from p 69):

1. Establish a global blue carbon fund for protection and management of coastal and marine ecosystems and ocean carbon sequestration, setting up mechanisms to allow the future use of carbon credits for marine and coastal ecosystems. Urgently upscale coastal zone planning and management especially near blue carbon sinks to increase the resilience of these natural systems and maintain food and livelihood security from the oceans.
2. Urgently protect at least 80% of remaining seagrass meadows, salt marshes and mangrove forests, through effective management and enforcement.
3. Initiate management practices that reduce and remove threats, and support the robust recovery potential inherent in blue carbon sink communities.
4. Maintain food and livelihood security from the oceans through comprehensive and integrated ecosystem approaches to increase the resilience of human and natural systems to change.
5. Implement mitigation strategies in the ocean-based sectors, including:

   a. Improve energy efficiency in the marine transport, fishing and aquaculture sectors, and marine-based tourism

   b. Encourage sustainable, environmentally sound ocean-based production, including algae and seaweed

c. Curtail activities that negatively impact the ocean's ability to absorb carbon

d. Ensure that investment for restoring and protecting the capacity of ocean's blue carbon sinks to bind carbon and provide food and incomes is prioritized in a manner that also promotes business, jobs and coastal development opportunities

e. Manage the coastal ecosystems to encourage rapid growth and expansion.

This is much less physical technology than an integrated management system involving international organizations, national government authorities, and ecosystem managements. Scientists have an obviously integral role to play, whether employed in the organizations themselves, in universities, or elsewhere. However, this case serves as another reminder not to overlook non-physical approaches when exploring how to tackle climate change. The heart of the issue here is to save some very important ecosystems which are under severe threat. There are no obvious physical technologies ready to tackle this.

Finally, there is a need to expand the scientific knowledge in this area. While our understanding of the $CO_2$ storage potential of some ecosystems is fairly complete (for example open-ocean phytoplankton populations), we need to improve our understanding of many other ecosystems (such as coral reefs). It will also be important to gain a better understanding of the fluxes of other greenhouse gases such as methane. For example, the removal of mangroves from the coastline will not only lead to a reduced capacity to store carbon dioxide, but it will also lead to a potential increase in the flux of methane and other related greenhouse gases into the atmosphere from anoxic (oxygen-starved) mud and other consequences of mangrove removal.[155]

## BIOTECHNOLOGY

Biotechnology is a technology domain based on biology, agriculture, food science, and medicine. It governs some technologies discussed in previous parts of this appendix, especially biofuels. It is important, however, to acknowledge the profoundly important role of biotechnology as a discipline, not just how it has influenced particular technologies.

While biotechnology is sometimes confused with genetic engineering, it encompasses a wider range and history of procedures for modifying living organisms according to human purposes, going back to domestication of animals, cultivation of plants and "improvements" to these through breeding programs that employ artificial selection and hybridization.

The United Nations Convention on Biological Diversity defines biotechnology as any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use. There are several branches of biotechnology, for example:

- Green biotechnology is biotechnology applied to agricultural processes. One hope is that green biotechnology might produce more environmentally friendly solutions than traditional industrial agriculture. An example of this is the engineering of a plant to provide its own pest control, replacing the need for external application of pesticides.

[155] This section benefits from comments by Ove Hoegh-Guldberg on a previous draft.

Whether or not green biotechnology products and associated issues of food security are becoming environmentally friendly remains a topic of healthy debate, which appears to be gradually leading to greater public acceptance of mainstream green biotechnology.

- Red biotechnology is applied to medical processes. Some examples are the designing of organisms to produce antibiotics, and the engineering of genetic cures through genetic manipulation.
- Blue biotechnology has been used to describe the marine and aquatic applications of biotechnology, but its use is relatively rare. [156]
- White biotechnology is biotechnology applied to industrial processes. It has been defined as "a set of long-term strategies in which living cells and enzymes will be used to produce goods and services to mankind, with a smaller burden on the environment, using renewable resources, and promising better products at lower production costs in terms of energy, water and capital costs ." (Villadsen 2007, p 6957).

White biotechnology research is progressing "at a tremendous pace", which according to Villadsen (2007) "makes it almost certain that none of the second-generation industrial plants for making solvents, intermediates for polymer production, or transportation fuels will be based on the same fundamental science as the first generation production plants." Costs have come down by a factor of at least five over the past decade, and even more for cellulosic ethanol technology as noted in the description of individual technologies.

Villadsen concludes (2007, p 6967): "The expansion of industrial biotechnology to substitute many of the traditional petrochemical routes to commodity chemicals is expected to be very rapid. First of all the expansion is driven by the advances in molecular biology where increases in yield and productivity of the order of a factor ten within a few years of dedicated research are not impossible. The enormous experimental work required to find the right organism and the best operating conditions is greatly helped by the development of new analytical systems, by robotics and by miniaturization of the experimental equipment. But an equally important role is played by the efforts of many academic research groups to set up and solve complex models of the metabolism of the organisms, and by data treatment methods that can handle both efficiently and correctly the enormous amount of data that result from the new experimental techniques.

It appears that the application of engineering principles and engineering intuition to develop new equipment for large-scale operation of bioprocesses is lacking behind. Consequently, many unit processes of considerable importance for the bio-industry are insufficiently researched, and are taught with lacking enthusiasm at many universities. To reap the full benefits of the scientific revolution in biology one must promote the parallel research and teaching in the engineering fields that relate to processes where enzymes and living cells are used as "chemical factories"."

In conclusion, white biotechnology research is progressing fast with support from big business, and there may also be paths towards future "green revolutions" like the one that added a quantum leap to agricultural productivity in the 1950s and 1960s. "The projects

[156] Wikipedia on biotechnology, as at October 2009.

within the Green Revolution spread technologies that had already existed, but had not been widely used outside industrialized nations – including pesticides, irrigation projects, synthetic nitrogen fertilizer and improved crop varieties developed through the conventional, science-based methods available at the time."[157] The next time around it is reasonable to expect that breakthroughs in modern biotechnology may provide a range of safer environmental solutions. Given that genetic engineering is part and parcel of mainstream biotechnological research, community attitudes will remain a factor, likely to differ in the four scenarios.

### NANOTECHNOLOGY

In 1959, Richard Feynman, who was to receive the Nobel Prize in Physics six years later for his contribution to quantum electromechanics, delivered a visionary lecture on micro-miniaturization, "the problem of manipulating and controlling things on a small scale" (Feynman 1959). It portrays nanotechnology, a then future technology not even named, in a nutshell.

Principally inspired by biology, he noted: "Biology is not simply writing information; it is doing something about it. A biological system can be exceedingly small. Many of the cells are very tiny, but they are very active; they manufacture various substances; they walk around; they wiggle; and they do all kinds of marvelous things – all on a very small scale. Also, they store information. Consider the possibility that we too can make a thing very small which does what we want – that we can manufacture an object that maneuvers at that level!" (p 5)

"When we get to the very, very small world .. we have a lot of new things that would happen that represent completely new opportunities for design. Atoms on a small scale behave like nothing on a large scale, for they satisfy the laws of quantum mechanics. So, as we go down and fiddle around with the atoms down there, we are working with different laws, and we can expect to do different things. We can manufacture in different ways.

Another thing we will notice is that .. all of our devices can be mass produced so that they are absolutely perfect copies of one another. We cannot build two large machines so that the dimensions are exactly the same. But if your machine is only 100 atoms high, you only have to get it correct to one-half of one percent to make sure the other machine is exactly the same size – namely, 100 atoms high!

At the atomic level, we have new kinds of forces and new kinds of possibilities, new kinds of effects. The problems of manufacture and reproduction of materials will be quite different. I am, as I said, inspired by the biological phenomena in which chemical forces are used in repetitious fashion to produce all kinds of weird effects (one of which is the author)." (p 9)

Fifty years after Feynman's visionary lecture, nanotechnology is flourishing in fields "as diverse as materials manufacturing, computer chips, medical diagnosis, biotechnology, energy and national security" (Esteban et al. 2008, p 10). University institutes devoted to nanotechnology research are found everywhere. Defining nanotechnology as "science and engineering resulting from the manipulation of matter's most basic building blocks: atoms

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[157] Wikipedia on the green revolution, as at October 2009.

and molecules", Esteban and his co-authors have explored the importance of the technology relative to climate change for the United Nations University Institute of Advanced Studies (UNU-IAS, based in Yokohama, Japan).

Nanotechnology is a "platform technology" (and a "domain" in Brian Arthur's (2009a) terminology) whose role if found technically and economically viable is to play an enabling role in other domains such as (Esteban et al. 2008, p 11):

- The hydrogen economy: hydrogen as an energy source using electrolysis and photolysis, automotive fuel cells, hydrogen storage in light-metal hydrides and carbon nanotubes, and molecular sponges which mop up $CO_2$. It could have a potential role in many applications of nano-engineering.
- Fuel efficiency: Fuel additives to catalyze fuel efficiency and reduce emissions such as cerium oxide powders and cerium salts which absorbs some $CO_2$ from the atmosphere, Improved lubricant additives to minimize corrosion and energy performance, nano-detergents to improve engine performance, nano-structured coatings for turbines, and catalytic converters.
- Photovoltaics and other solar energy: nano-particle silicon systems; mimicking photosynthesis; nano-particle encapsulation in polymers; use of non-silicon materials such as calcopyrites to develop thin film technology; molecular organic solar cells; organic polymer photovoltaic systems; development of single-walled nanotubes in conducting polymer cells; nitride solar cells; flexible film technology; and development of novel nano-structured materials.
- Energy storage: For electric and hybrid cars, supercapacitors, electric trains, trams and trolley buses; batteries for portable consumer information and communication technology, such as laptops and mobile phones.
- Insulation: Insulation for buildings to save on heating and cooling; foam insulation including aerogels in the nanometer range characterized by their thermal properties and extremely low density; glass fibers, glass, and vacuum insulating panels.

Nano-catalyst materials can also give better selectivity for chemical reactions and thereby save raw materials and investment costs.

While there are potentially many benefits offered by nanotechnology for responding to climate change, there are also potential risks that nanotechnologies present to humans. As nanotechnologies are an emergent field of science and technology, the risks to humans, animal health and the broader environment cannot yet be determined. "The most significant issues raised so far relate to the toxicity of manufactured nano-particles and their ability to enter the human body and reach vital organs via the blood. However, there are still significant gaps in knowledge about how nano-particles act, their toxicity and how to measure and monitor nano-particle exposure." (Esteban et al. 2008, p 16)

"Given the sophisticated and expensive nature of nanotechnology R&D, there are also ethical issues raised concerning the ability of less developed countries to benefit from and sustainably manage such advances in technology. What is unclear is whether less developed countries will be able to readily access this new technology, and perhaps more importantly, whether they have the capacity to properly assess and manage potential risks." (p 17)

In conclusion, nanotechnology is or will be making useful contributions to particular applications like those mentioned in the dot points above. It is less likely to help solve any large-scale structural change toward renewable energy sources, and there may be problems diffusing nanotechnology to the smaller less-developed countries and regions.

## TECHNOLOGY DIFFUSION

### OVERVIEW

Brian Arthur's focus is on the nature of technology, the title of his book (Arthur 2009a). In our context, apart from considering possible technologies that may "save the world" by reducing greenhouse gas emissions, there is another critical issue – how diffusion of technologies may also help "save the world". This means focusing on the developing world, with special reference to the fifty least developed countries, of which two-thirds are in Sub-Saharan Africa. "The two greatest problems of our times – overcoming poverty in the developing world and combating climate change – are inextricably linked" (Stern 2009, p 8).

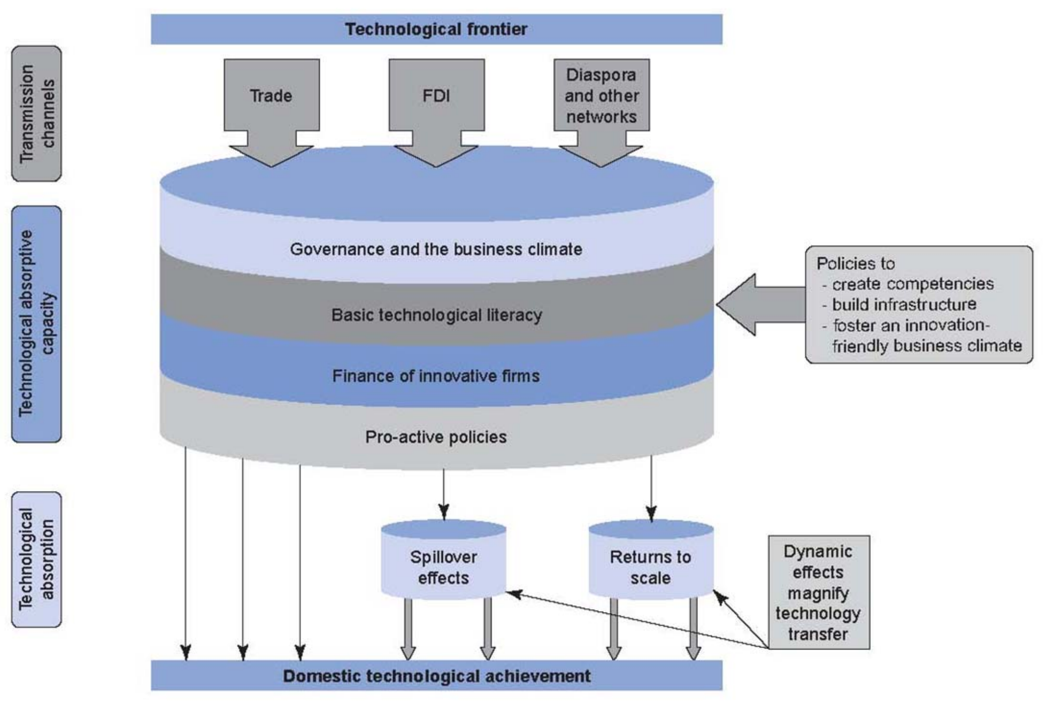
Technology typically spreads across the world through trade, foreign direct investment, and communications between organizations, academics, and expatriates across the borders. Major innovations and inventions, which are the cutting edge of technological change, tend to take place in high-income economies. Whether these patterns are changing is a main concern in this section.

The World Bank publishes an annual report on *Global Economic Prospects*, with a special theme each year, backed by empirical research. In 2008 the theme was technology diffusion to the developing world (Burns et al. 2008). The report found that up-front innovation and invention is largely carried out by high-income countries, dominated by the OECD. Even the 46 countries classified as "upper-middle income" accounted for very little – countries including Argentina, Brazil, Chile, Hungary, Malaysia, Mexico, Poland, Russia, South Africa, and Turkey.

To become involved in research, people born in developing countries move to high-income countries; the report notes that 2.5 million of the 21.6 million scientists and engineers working in the United States were born in developing countries. This itself must provide a source of technological inspiration across the borders, and therefore a likely source of innovative advance in developing countries.

China and India are included among the developing countries which according to the World Bank report generate little original innovation (a view challenged below), but the level of aggregation prevents any analysis of differences within countries, and the World Bank report acknowledges that there are at least pockets of innovative technology: "Despite a level of technological achievement in major cities that can rival that in high-income countries, low levels of technological advancement in rural areas mean that, viewed as a whole, countries such as China and India are not particularly technologically advanced. Moreover, because technology spreads slowly across firms, there are wide differences in the technological sophistication of production, even within the same sector in the same country. " (p 52).

This report finds that more new technology is beginning to develop independently in these countries. In upper-middle income countries the gap is already narrowing, especially in




*Source:* World Bank.

*Figure 3: Stylized description of how a developing country absorbs technology. An economy is exposed to higher-tech business processes, products, and services through foreign trade, foreign direct investment, and contacts with its diaspora and other networks such as academia and international organizations (the large arrows at the top of the figure). The larger these flows, the greater the exposure of the economy to the global technological frontier.*

*However, exposure to new ideas and techniques is not sufficient to ensure that the technology diffuses through the economy. Successful absorption of foreign technology depends on the technological absorptive capacity of the economy (represented by the multiple-ringed drum). This capacity depends on the overall macroeconomic and governance environment, which influences the willingness of entrepreneurs to take risks on new and new-to-the-market technologies; and the level of basic technological literacy and advanced skills in the population, which determines a country's capacity to undertake the research necessary to understand, implement, and adapt them. Because firms are the basic mechanism by which technology spreads within an economy's private sector, the availability of finance for innovative firms through the banking system, remittances, or government support schemes is also important for the speed of the absorption process.*

*Finally, pro-active government policies are crucial. Governments are often the primary channel through which technologies are delivered. Moreover, government policy is largely responsible for creating a business environment that facilitates easy entry and exit and that is not hostile to the profits to be made from exploiting new technologies.*

[From Burns et al. (2008), pp 8-9. Reprinted with permission from the World Bank as copyright holder.]

Hungary, Poland, and Chile during the past 10 years (Burns et al. 2008, p 52). But before going further, we need to present the World Bank's model.

## THE WORLD BANK APPROACH

"In exploring technological achievement and diffusion, the World Bank report adopts a broad definition of technology and technological progress, one that encompasses the techniques (including the way the production process is organized) by which goods and services are produced, marketed, and made available to the public. Understood in this way, technological progress at the national level can occur through scientific innovation and invention; through the adoption and adaptation of preexisting, but new-to-the-market, technologies; and through the spread of technologies across firms, individuals, and the public sector within the country." (Burns et al. 2008, p 2)

Figure 3 is reproduced with World Bank permission, with explanations from the source added below the diagram. Generally: "A central finding of the report is that most developing countries lack the ability to generate innovations at the technological frontier." (p 3) "The bulk of technological progress in developing countries has been achieved through the absorption and adaptation of pre-existing and new-to-the-market or new-to-the-firm technologies, rather than the invention of entirely new technologies." (p 7)

The main empirical results of the World Bank research are:

1. The technological frontier has advanced as high-income countries continue to outperform developing countries at a rapid pace with basic innovations, so the innovative technology gap remains large between high- and low-income countries.
2. Developing countries have progressed markedly in the past 15 years. As a result, technological achievement (as distinct from innovative or inventive technology) has advanced more quickly than in high-income countries.
3. The convergence of technical achievement reflects substantial improvements in the openness of developing countries to foreign trade, foreign direct investment, and international migration. This has dramatically increased both the exposure of developing countries to new technologies and their opportunity to use foreign markets and exploit increasing returns to scale.
4. Absorptive capacity has progressed through improved literacy and education, and better macroeconomic stability. But progress in improving the business climate and governance indicators has been much more mixed. This has put a restraint on the technological absorptive capacity of developing countries, at least for now.

The research covered two periods, the early 1990s (1990-93) and the early 2000s (2000-03). The comparison reveals some significant developments, including strong growth from a very low base for developing countries (Figure 4). The top panel shows the *level* of technological achievement split between innovation/invention and penetration of older and recent technologies. The older technologies are fixed-line telephony, electric power, transportation, and health care services. The recent technologies are the Internet, personal computers, cell phones, percentage of digital mainline, and high-tech exports.

| *Penetration* ⟶ | Scientific innovation and invention | Older technologies | Recent technologies |
|---|---|---|---|
| **A: Technological achievement** | | | |
| High-income countries | 100.0 | 100.0 | 100.0 |
| Upper-middle income countries | 3.3 | 58.4 | 49.6 |
| Lower-middle income countries | 0.6 | 41.6 | 31.8 |
| Low-income countries | 0.1 | 23.7 | 22.7 |
| **B: Increase in technological achievement** | | | |
| High-income countries | 100.0 | 100.0 | 100.0 |
| Upper-middle income countries | 191.6 | 220.8 | 162.3 |
| Lower-middle income countries | 157.1 | 251.8 | 145.8 |
| Low-income countries | 63.7 | 480.4 | 411.3 |

*Figure 4: The top panel shows the technological achievement in developing countries relative to that in high-income countries, as percent of the level in high-income countries. Innovative and inventive activity is very low in the rest of the world, and introduction of technologies has been largely through older and recent technologies developed elsewhere. The bottom panel shows the* ***increase*** *in technological achievement between 1990-93 and 2000-03, using the change in high-income countries as an index. Though still low, the rate of growth in middle-income countries exceeded the growth in high-income countries, but this was not the case for low-income countries. These countries, however, showed much higher growth than any other country group in importing both older and recent technologies.*

Source: World Bank, reproduced from Tables 2.11 and 2.12 in Burns et al. (2008, p.81).

The lower panel shows the *change* between the early 1990s and the early 2000s, with two quite remarkable findings:

- The introduction of innovation and invention in upper-middle income countries almost doubled relative to the high-income countries, and was almost 60% up in the lower-middle income countries, albeit from very low bases. Only the low-income countries did not perform as well as the developed countries on this criterion.
- The low-income countries, however, produced the second remarkable finding. For both older and more recent technologies, they showed by far the greatest growth (between four- and five-fold) relative to the high-income countries, indicating considerable catch-up. Middle-income countries also showed high relative growth of some 250% for older technologies and 150% for recent technologies. The relative growth was generally higher for older than for recent technologies, presumably because growth rates were high for the latter in the high-income countries too.

The World Bank report (Burns et al. 2008) contains an analysis of a comprehensive data set called CHAT (Cross-country Historical Adoption of Technology) compiled by the National Bureau of Economic Research, which traces the extent of diffusion of some 100 technologies in 157 countries between 1750 and 2003 (Comin and Hobijn 2009). The report notes two important points emerging from this analysis:

- First, technology diffusion across the globe has accelerated over time. For transportation, communications, and manufacturing technologies discovered between 1750 and 1900, it took an average of 107 years before they reached 80% of countries covered by the analysis. The average declined to 61 years for technologies discovered between 1900 and 1950, 24 years for those discovered between 1950 and 1975, and 16 years for those discovered between 1975 and 2000. There are similar patterns within each of the three technology groups, and for medical technology which covered OECD countries only. [158]

- Secondly, technological diffusion appears to accelerate above a certain threshold, defined as a percentage of the average level of the 10 countries where the technology is employed most intensively.

  For the world as a whole, the amount of time required to go from the 5% level to the 25% level is much smaller than the time required to reach the 5% level. Between 1900 and 1950, it took an average of 52 years to reach the 5% threshold, but only an additional 13 years to reach 25%. Moreover, the pace of acceleration has increased over time. For technologies introduced since 1975, dominated by electronics and information technology, it took an average of 16 years from its invention for a technology to reach the 5% threshold in a given country, but only another three years to reach the 25% threshold.

### INDICATIONS OF EXPANDING DIFFUSION RATES

A special report in *The Economist* on innovation in "emerging markets" (what used to be called "the developing world" or even "the third world") contains the clearest indication yet that innovative effort is spreading rapidly and that the "emerging world" now rivals the rich countries for business innovation (Wooldridge 2010). Before that article was published, the current section of Appendix 6 (unchanged except for this and the next paragraph) had already found plenty of evidence that the World Bank report was rapidly becoming outdated.

There are now around 25,000 multinationals based in the emerging world according to the United Nations. "The best of these .. are as good as anybody in the world. The number of companies from Brazil, India, China or Russia on the *Financial Times* 500 list more than quadrupled in 2006-08, from 15 to 62. Brazilian top 20 multinationals more than doubled their foreign assets in a single year, 2006." (Wooldridge 2001, p 3 – the 16-page special report is recommended reading in full).

In contrast, the World Bank report suggests that within its long-term perspective (to 2030), inventive ability will remain largely with the high-income countries. This is highly debatable. Anyhow, the time perspective adopted in the World Bank report is much shorter than for the four IPCC-based scenarios, and our assumptions must vary with each storyline.

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[158] Cataract surgery holds the record among the technologies listed in the World Bank report, taking 251 years to reach 80% of countries. The technique goes back to antiquity but Jacques Daviel performed the first successful extraction in Europe in 1748 (Wikipedia). This suggests that 80% country penetration was not reached until the end of the 20th century.

The indicators of technological innovation and invention are the number of scientific journal articles and United States and European patents granted per million population. The report itself comments on some shortcomings of these,[159] and they also appear to be at loggerheads with Brian Arthur's organic and evolutionary model (Arthur 2009a), according to which innovations give rise to other building blocks of innovations in an continuing process .

The complexity should be duly acknowledged. Bhidé (2009) in an exposé on "the three levels of technology" comes to similar results as Arthur (2009a), who was described in Appendix 5 as a leading exponent of complexity theory. Using computers as an example, there are high-level building blocks or raw materials (microprocessors and the silicon used to make them), mid-level intermediate goods (motherboards and their components), and ground-level final products (the computers themselves). Furthermore, the invention would not see the light of day without know-how ranging from high-level understanding of solid-state physics, through knowing at mid-level about circuit designs and chip layouts, to maximizing yields and quality in semiprocessor  fabrication plants at ground level.

Not only does the new invention depend on the other levels of technology developing the appropriate support technologies. It would not sell very effectively without adjustments to organizational and marketing technologies ("purposed systems" in Arthur's terminology). Finally, globalization has caused innovation and technological development to become much less dependent of a particular nation, which is important for our understanding of diffusion:

"In a world where breakthroughs travel easily, their national origins are fundamentally unimportant. .. An Englishman invented the World Wide Web's protocols in a Swiss lab. A Swede and a Dane started Skype, the leading provider of peer-to-peer Internet telephony, in Estonia. .. What is true for breakthroughs from Switzerland, Sweden, Denmark, and Estonia is true as well for those from China, India, and other emerging economies. We should expect – and desire – that as prosperity spreads, more places will contribute to humanity's stock of scientific and technological knowledge. The nations of the earth are not locked into a winner take-all race for leadership in these fields: the enhancement of research capabilities in China and India, and thus their share of cutting-edge work, will improve living standards in the United States, which, if anything, should encourage these developments rather than waste valuable resources fighting them." (Bhidé  2009, p 4)

Anecdotal evidence gathered through the review of technologies in the previous sections suggests that the western dominance may be in for some competition. The development of the bioethanol industry based on sugar cane was said to be based to a large extent on Brazil's own technology research (Goldemberg 2007); even if this research was arguably derived from basic research undertaken elsewhere, it may at the very least contain the germs of future basic research in Brazil.

[159] "Finally, most indicators tend to be biased toward goods (as opposed to services), and among these, toward electronic and other high-tech goods. Most measures also focus on product technology (goods and services that themselves are highly technical) rather than final (or intermediate) goods and services that may be technologically unremarkable, but which are the result of a technologically sophisticated production process, for example, maize that is produced using sophisticated crop rotation methods, enhanced irrigation and fertilization strategies based on satellite imaging, and bioengineered seeds." (Burns et al. 2008, p 60)

Writing on "white" (industrial) biotechnology, Villadsen (2007, p 6958) notes: "China will .. supplant much of its fossil fuel import with bio-fuels, but the momentum of Chinese investments in research will soon make China one of the foremost exponents of a bio-based economy. India, China, Japan, Korea, and even the smaller economies of South East Asia seem to be bristling with ideas for bio-based routes to fine chemicals production."

John Villadsen is a leading academic biotechnologist with a lifetime of experience with industries in Latin America, Asia, and elsewhere. Two years after the paper quoted above, he summed the current situation and prospects up in his own professional field, referring to those countries where he has most recent experience: [160]

- In Brazil, the burgeoning bioethanol industry will accept that both the primary product, sugar, and the 80% of the plant that is not sugar must be utilized for ethanol production. Then Brazil will develop a large chemical industry where most of the valuable clean sugar is used to produce chemicals, while a large export of ethanol is maintained based on the rest of the biomass. This enormous change will continue to require innovations developed in Brazil.
- India is "a kettle boiling over with new ideas." Its 15 so-called IITs (Indian Institutes of Technology) are "brilliant". They were all founded (or upgraded to IITs) since 1950 and six new IITs were opened in 2008 alone. Three more are being planned.[161]
- Thailand is "massively into biotechnology, including academic research of a high caliber." The National Center for Genetic Engineering and Biotechnology (BIOTEC) is under the umbrella of the Thai Government's National Science and Technology Development Agency (NSTDA). A 80-acre Thailand Science Park outside Bangkok provides main laboratories, incubator units, pilot plants, greenhouses and accommodation as well as financial, management and legal support for NSTDA, BIOTEC and private customers. Its main objective is to develop the capability for conducting research, development and engineering in the area of genetic engineering and biotechnology.[162]
- Leading Danish multinational companies Novo Nordisk (biopharmaceuticals, with a leading position in diabetes care) and Novozymes (which focuses on second-generation bioethanol from waste and agricultural residue with an ambition to "drive the world towards sustainability") place much of their research and development work in India and China where they collaborate with highly skilled scientists and technologists. China is becoming a strategically important market for both insulin and industrial enzymes.
- These companies, and others, support the new developments, believing that much new research into biotechnology will happen in countries not expected, some decades ago, to ever reach the innovative activity in North America and Western Europe.

There are further indications that the findings of the World Bank report undervalue a rapidly changing situation, especially in China. The Chinese Ministry of Science and Technology

[160] From Nielsen, Villadsen and Lidén (2010, Chapter 2), supplemented by information on IITs and Thai activities.

[161] Wikipedia on Indian Institutes of Technology.

[162] http://www.business-in-asia.com/thailand_biotechnology.html.

describes a rapidly expanding science and technology sector increasingly innovative in its own right. An issue of the Ministry's *Newsletter* celebrating the 60 years since the formation of the People's Republic shows that the number of Chinese journal papers in 2008 achieved third place in the Thomson Reuter's Science Citation Index, and that Chinese innovation grants (presumably meaning patents) came fourth. The number of journal articles and international patents are the prime components of the World Bank's own indicators of innovation.[163]

When the country was opened up, the development of Chinese science and technology was initially based on imported advanced technologies, but it now enjoys an innovative capability in emerging technologies, including new energy. The fast development of high-tech businesses backed by national science parks "has made China's high-tech industry a promising industry with huge perspectives." The sheer size of the industry is impressive: 42 million science and technology personnel including "a high caliber R&D contingent of 1.9 million person/year."

Other issues of the Chinese *Newsletter* describe the high-level cooperation between the United States and China in 2009, starting with Energy Secretary Steven Chu's visit in July which resulted in the establishment of the China-US Clean Energy Research Center on July 15. There are numerous other mentions of international cooperation, including at least two in nanotechnology (Denmark, Australia), cooperation on information technology with Europe, and a general effort to diffuse energy efficiencies and environmental protection technologies (with Japan and Korea). In July China launched its Golden Sun Pilot Project to speed up 500+ megawatt photovoltaic solar projects. Also in July, Fengfa Technology in Shenzhen put the world's first semi-direct drive wind turbine at the megawatt level on public display. This involved new technologies resulting in 24 patents.

The World Bank report itself contains several more examples of innovative activities in the developing world:

- Examples from Chile, Kenya, and Indonesia show that technological innovation may spur further innovation in upstream and downstream activities (Burns et al. 2008, p 56).
- "Increasingly, venture capitalists and "business angels" are playing a role in financing new technologically sophisticated firms in developing economies. .. Even though empirical evidence is still scarce, this activity appears to be translating into increased innovation. .. Western-based venture capitalists are increasingly becoming involved in markets in Asia (China and India), Eastern Europe (notably the Czech Republic, Hungary, and Russia), and South Africa." (p 140)
- Government-sponsored innovation of Brazilian biofuels is behind the flex-fuel car engine, which can run on any combination of ethanol and gasoline. It was introduced in 2002 and, along with the surge in crude oil prices, has led to a revitalization of ethanol in Brazil (p 144).
- Petrobras in Brazil is now recognized as a world leader in all phases of deepwater petroleum technology (p 62).

[163] Newsletter No. 562 (October 30, 2009). (http://www.most.gov.cn/eng/newsletters/2009/index.htm).

- The Korean government program of technological development and innovation financing includes research centers located within corporations to supply industry with high-tech research capability. Industry dictates the focus and area of research. (p 145)
- The technological diversity across Chinese or Indian provinces was not picked up in the aggregate measures developed by the World Bank. Large technologically sophisticated cities, such as Mumbai or Delhi, are being well ahead of areas that lag behind in economic development (p 60). OECD has estimated that 70% of high-tech trade (both imports and exports) in China originates in four regions (Guangdong, Jiangsu, Shanghai, and Beijing) and is highly correlated with R&D intensity and foreign firms (p 112).[164]

The process of technology diffusion has entered a significant new stage, which is important in any assessment of the future. The major technologies originally adopted throughout the world included fixed-line telephony, electric power, transportation, rail and road infrastructures, educational institutions, sanitation networks and health care services – all expensive to create and maintain, and relying on large numbers of individuals with mainly modest technical skills. These older technologies depend on what governments have delivered in the past – mainly education and basic infrastructure (pp 4-5).

Older technologies, however, remain vitally important for food security: better roads for transporting produce, better storage facilities to reduce waste. This point was made prominently at the start of the section on land management technologies. One thing is to manage the land, another to distribute and market the produce effectively and profitably.

The penetration of newer technologies such as mobile phones, computers, and the Internet has been considerably faster. The infrastructure is cheaper and requires fewer (though more skilled) workers to maintain. Moreover, costs are being dramatically reduced, in a continuing process. In many countries, the private sector can now offer these services in a competitive environment in contrast to the state-owned, monopolistic environments of the past. Furthermore, demand for these products has been boosted by low end-user costs as a result of competitive pricing strategies and because some of these newer technologies lend themselves more easily to sharing than do some older technologies (pp 5-6).

### IMPLICATIONS FOR THE WORLD'S LEAST DEVELOPED SOCIETIES

Village-based technological development may have the best chances of improving the conditions of the world's poorest, many living in traditional village societies. Two developments in particular look encouraging.

[164] The OECD publication is Liu and Remøe (2007). In general, the regions on the east coast are more innovative than the provinces in the central and western parts of China. Regional levels of innovation are highly correlated with their GDP per capita and their contribution to high-technology exports, but less with their shares in national R&D expenditures (p 26). The benefits of economic development are unevenly distributed across regions and between urban and rural populations. Large migration flows to urban areas exert pressure on the social fabric and the environment (p 59). The rapid development of small technology-based firms is an encouraging trend, which is partly a pay-off from the huge investment China has made in the development of science parks and incubators. Many of these small firms remain dependent upon public support to tenants of science and technology parks. But there is a recent emergence of more purely market-based innovative networks of small firms in some regions, notably Zhejiang, Jiangsu and Guangdong (pp 31-32).

First, the Grameen Bank originated in 1976 when Bangladeshi economist Muhammad Yunus launched a research project to extend banking facilities to the poor in Bangladesh, providing micro-enterprise loans to villagers, especially women. The aim was to enable households to reverse the vicious circle of low income, low savings, low investment, also known as the poverty trap.

In September 2009 the Grameen Bank had 7.95 million borrowers, 97% of whom were women. The bank has grown to 2,559 branches, works in most of the country's villages, and the loan recovery rate is 98%.[165]

Grameen Foundation, a nonprofit organization headquartered in Washington, DC with an office in Seattle, Washington, was founded in 1997 by friends of Grameen Bank to help microfinance practitioners by spreading Muhammad Yunus's philosophy worldwide. The Foundation has no financial or institutional links with the Grameen Bank. It is active in Sub-Saharan Africa, Asia, Middle East/North Africa, and the Americas, and concentrates on helping poor people, mostly women and children, improve their lives.[166]

Secondly, cell phones have evolved in a few short years to become tools of economic empowerment for the world's poorest people, compensating for inadequate infrastructure, allowing a freer flow of information, making markets more efficient, and unleashing entrepreneurship. Mobile density (cell phones per 100 persons) reached 100% in South Africa in 2009, and 98% in Ghana, and is reported to have reached 40% for total Africa.[167] The impact on communications and village economies generally is dramatic, covering everything from agricultural information services to matching sellers and buyers of agricultural produce and commodities.

This development is paralleled by a strong increase in mobile broadband subscribers, a technology that is expected to surpass the number of fixed broadband subscribers and to extend the use of the Internet to the whole of humankind. Hamadoun Touré, secretary-general of the International Telecommunication Union, says that the next task is to ensure that everyone who wants to can use mobile technology to access the Internet. Like many in the industry, he predicts that this will be done using low-cost laptops ("netbooks") connecting to the Internet via mobile networks. After further cost reductions to below $100, this could evolve into a village-netbook model, the Internet equivalent of the village-phone model. It would provide a stepping stone to wider Internet access in the poorest areas, just as village phones did for telephony (Standish 2009).

These developments are among the most dramatic in the fight to reduce the poverty of the least developed countries. There seems to be a whole cluster of associated special technologies which might in time develop into a new technological domain in Brian Arthur's terms (Arthur 2009a).

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[165] http://www.grameen-info.org/index.php?option=com_content&task=view&id=26&Itemid=0. Muhammad Yunus and Grameen Bank jointly received the Nobel Peace Prize in 2006, and Dr Yunus was one of 16 recipients of President Obama's 2009 Medal of Freedom.

[166] http://www.grameenfoundation.org/who-we-are.

[167] This does not mean that 40% of every person has a cell phone, as one person can own more than one handset or SIM-card..

A special investigation of policy options for sustainable energy development for Africa (Chapter 1 of Takada et al. 2007) presents a large canvas, leaving no doubt that the task is difficult (p 4), despite the new developments just described:

"Over the last four decades, the gap between energy supply and demand in Africa has been growing. Projections by experts in the field forecast that this gap will continue to grow, and the livelihood of more Africans will continue to be critically impaired by energy poverty, that will seriously slow down the socioeconomic development of the continent. Energy has been supplied in insufficient quantity, at a cost, form and quality that has limited its consumption by the majority of Africa's population, making the continent the lowest per capita consumer of modern energy of all regions of the world. The challenges are indeed daunting, and more than ever, a concerted effort by all actors is required to achieve any significant progress."

Given this challenge, the report sees a relatively promising future for renewable energy supplies and, equally importantly, increased energy efficiency, provided the energy supply sector is liberalized (as in Europe) to encourage private enterprise. The timing of such a change is assisted by an increased urgency to encourage sustainable development and combat climate change, and the growing availability of new technology (p 8).

Currently, fuel-wood is used throughout Africa as renewable energy, there is large and well-established hydropower capacity across the continent and geothermal power generation is established in the Rift Valley of Kenya. Apart from such "established" energy supplies, "new" technologies that have been commercialized worldwide in the last 30 years include wind turbine electricity, solar photovoltaic electricity, small hydro plant, and a wide range of secondary biofuels. Especially in North Africa, there is considerable expectation of relatively large scale generation of electricity from solar photovoltaic.[168]

Nevertheless, to date in Africa, most experience of the new renewables relates to small-scale installations, especially for stand-alone rural electricity. The potential is very large, but there are few African countries with comprehensive legislation to link liberalization of national utilities with increase of renewable energy from local and national resources (p 16).

Basically, energy supply is needed for heating, transportation fuel and electricity. Within each category, a range of renewable energy technologies has become reliable and cost-effective, and accepted for successful business and industry. Examples are: (p 18)

- Heating: solar water heaters, passive solar building design (also incorporating cooling), biomass crops and waste, biogas, geothermal sources, heat pumps.
- Transportation fuel: bioethanol and biodiesel, the latter based on feedstock such as sunflower, canola, and coconut. South Africa has a program to produce bioethanol from fermentation of molasses as a by-product of the sugar cane industry (using the by-product bagasse as fuel), and from fermentation of yellow maize. It will also produce biodiesel from palm oil and jatropha. [169] (p 19)

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[168] The environmental impact of large-scale solar installations in the Sahara is not discussed.

[169] A perennial poisonous shrub originating in Central America but mainly grown in Asia and Africa, where it is used as a living fence to protect gardens and fields from animals. It contains an average of 34% oil, which can be processed to produce a high-quality biodiesel usable in a standard diesel engine (Wikipedia on *Jatropha curcas).*

- Electricity: solar photovoltaic, wind, hydro (including run-of-the-river), geothermal, biomass thermal generation, biofuel engine generators.

The report notes that Africa has not to date introduced much clean technology despite the potential for doing so, and energy efficiency remains low. "The crux of the matter for Africa is that energy supplies are in practice limited and very expensive in proportion to available income. It makes sense to improve the energy efficiency, so costs reduce and productivity increases." (p 15) It lists many opportunities regarding heating, transport and other applications of energy supply, not only in improving the efficiency of supplying energy, but also improving the efficiency of the use of the energy – end-use efficiency (pp 21-24).

The report (Takada et al. 2007) is basically concerned with energy for electricity, heating and cooling, and transport as sustainable development options, rather than land management in the sense discussed in this appendix. The only reference to land use relates to the need for urban layout to benefit the types of transport that are important to the urban poor: walking, cycling, animal traction, and public transport (p 40).

Looking at Africa, especially Sub-Saharan Africa, provides an opportunity to view the issues from the least privileged part of the world. The issues change from country to country according to degree of development, geography, climate, population structure, poor versus more well-to-do and rural versus urban regions, and a host of other criteria. There would not be any nation, however, where land management issues are unimportant in the fight against climate change, and this would apply especially strongly to the poorest nations.

The recent publication of *Blue Carbon* provides a final but very timely reminder that the preservation of marine-based carbon sinks is as important as forestry and other terrestrial sinks. This includes Africa, where mangroves are prevalent on the east coast from Mozambique to Kenya, on the west coast of Madagascar, and along the Red Sea, and on the Atlantic side from Angola to Senegal. Seagrasses are found from South Africa to Somalia and northwest Madagascar, and more intermittently on the west coast from Nigeria to Ghana and off Sierra Leone, Guinea, and the Canary Islands. Salt marshes are less prevalent, mainly occurring in South Africa and Angola (Nellemann et al. 2009, pp 36-37).

## ADDENDUM: THE NATURE OF TECHNOLOGY

Brian Arthur's book (2009a) is important for understanding how technologies evolve, and therefore for understanding how future technologies may emerge. This note summarizes his thesis with a possible bias towards our scenario-planning purposes. An endnote outlines his three "laws", which are relevant for understanding the future of technology (Arthur 2004).

Arthur distinguishes between *individual technologies* ("technologies-singular") such as a jet engine or radar, and *domains* ("technologies-plural") such as electronics, radio engineering or biotechnology. *Invention* or *radically new technology* is also obviously important. How they link up is described below, but first we must note the inspiration from the two most quoted persons in his book: Charles Darwin[170] and Joseph Schumpeter.

### COMBINATORIAL VERSUS BIOLOGICAL EVOLUTION

Technologies *evolve* in the sense that they all, including the novel ones called inventions, descend in some way from the technologies that preceded them. Arthur defines technological change as a organic process, giving it a living quality. Technologies are "ecologies" with components and practices that must fit together at any time, that change constantly as new elements enter, and throw off little sub-colonies from time to time that have a different quality. This provides a parallel to biological evolution, a link which according to "Arthur's Second Law" (see endnote) will strengthen in the 21$^{st}$ century.

In genetic evolution, new combinations are created in incremental steps which must produce a living organism at all stages. This does not work in technology. Schumpeter said in his *Theory of Economic Development* (1912, 1934): "Add successively as many mail coaches as you please, you will never get a railroad thereby." Rather, every novel technology and solution is a *combination* of parts from preceding technologies, facilitated by the constant capture and harnessing of natural phenomena that make the technology possible. In technology, Darwinian-type variation and selection happen when technologies are adapted to practical applications through engineering design, refining already formed structures.

Arthur acknowledges Schumpeter for the thoughts he first developed a century ago in his theory of economic development, discussed in our Appendix 5 under the heading *complexity theory and complexity economics*. The central concept is that economic development is an *endogenous* force, coming from *within* the economic system (Elliott 1983).

Schumpeter's theory that change in the economy arises from "new combinations of productive means" translates into "new combinations of technology" in modern terminology (Arthur 2009a, p 19). Schumpeter, of course, was almost alone among economists with his dynamic views on the integral role of technology. Arthur is one of a growing band of contemporary economists who have come to a similar view (no doubt aided by his polymath background in engineering, operations research, and complexity theory): "The overall

[170] Arthur has written another overview (2009b) concentrating on demonstrating the difference between Darwinian evolution and the combinatorial evolution of technology ("evolution 2.0").

collection of technologies bootstraps itself upward from the few to the many and from the simple to the complex. We can say that technology creates itself out of itself." (p 21)

### INDIVIDUAL TECHNOLOGIES

Individual technologies are means to fulfill a human purpose. The means can be processes or devices, which are the same thing at different levels: A technology embodies a series of processes – its "software". These operations require physical equipment to execute them – its "hardware". If we emphasize the software, we see a process or method. If we emphasize the hardware, we see a physical device.

Individual technologies are based on three principles:

1. C*ombination*: Every technology consists of parts organized around a essential idea that allows it to work. The primary structure consists of a main assembly that carries out the base function of the technology, and supporting subsystems.
2. *Recursiveness*: A technology consists of component building blocks that are themselves technologies, and these consist of sub-parts that are also technologies, in a repeating (recurring) pattern. These hierarchies can have several layers, all parts needing to be mutually compatible, which adds to the time and cost of developing new technologies.
3. *Phenomena*: A technology is always based on some phenomenon or phenomena that can be exploited and used for a purpose. Capturing phenomena is the basis of all physically based technologies, and helps explain their evolution: more sophisticated phenomena such as quantum effects could not have been uncovered without the prior discovery of the electrical phenomena.[171]

There are actually two types of "technology" in the sense that they represent means to fulfill a human purpose. Technologies such as radar or electricity generation are based on physical phenomena. But there is a huge range of other means of fulfilling human purposes such as business organizations, legal systems or contracts which are based on non-physical effects: organizational, behavioral, and even logical or mathematical procedures such as algorithms. These are also "technologies", or at least first cousins within the class of *purposed systems.*[172]

*Science* is also a purposed system, and it is vitally important in the evolutionary process because science and technology co-exist, or "co-evolve", in a symbiotic relationship. Modern science provides the formal uncovering of new phenomena and the understanding and knowledge of these phenomena. Technology builds from harnessing the phenomena which nowadays are being almost exclusively uncovered by science, but it also supplies the instruments and methods and experiments that science needs to develop its knowledge.

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[171] The dawn of electricity was in ancient Greece in 600 BC when one of the founders of Greek philosophy, Thales of Miletos, discovered the *phenomenon* that amber could be charged by rubbing (*electron* was the Greek word for amber). The Greek civilization itself could not have emerged without the prior evolution of primitive technologies based on fire, flint, and obsidian, and the technologies of the subsequent Neolithic revolution, which eventually enabled the city states of early recorded history to develop.

[172] Infrastructure is a related concept. Originally referring to public works from roads and bridges to schools and hospitals, it is now defined as the physical *and* organizational structure needed for a society or enterprise.

## DOMAINS

As families of chemical, electrical, quantum or other phenomena are harnessed, they give rise to bodies of technologies that work naturally together (*domains*). They differ from individual technologies such as radar, which achieve particular purposes. A domain ("technology-plural") is a toolbox of useful components to be drawn from, a set of practices to be used. Domains are more than the sum of their individual technologies and operate in a different way from these. They determine what is possible in a given era, and what become the characteristic industries of an era. There is nothing static about this. What can be accomplished constantly changes as a domain evolves and as it expands its base of phenomena.

Engineers play an important role as designers of individual applications requiring new combinations of components to achieve a specific purpose. The specialized designs combine to push an existing technology and its domain forward. In this way, experience with different solutions and sub-solutions steadily accumulates and technologies change and improve over time. Engineering therefore makes important contributions to the evolution of technology and to future innovation.

## THE ORIGIN AND DEVELOPMENT OF NOVEL TECHNOLOGIES

How do radically novel technologies arise – technologies using new or different principles for a particular purpose (the equivalent of new biological species)? Laser printing differs in kind from line printing technology, jet propulsion from propelled aircraft engines, and computation using electronic relay circuits from computation using electro-mechanic means. The new technologies use principles that are "radically novel" – they are *inventions*.[173]

A radically novel technology, however, *always* emerges from an accumulation of previous components and functionalities already in place. It is the culmination of a progression of previous devices, inventions, and understandings that led to the new technology. Supporting any novel device or method is an underlying *pyramid of causality*: of other technologies that used the principle in question; of antecedent technologies that contributed to the solution; of supporting principles and components that made the new technology possible; of phenomena once novel that made these in turn possible; of instruments, techniques, and manufacturing processes used in the new technology; of previous craft and understanding; of the grammars of the phenomena used and of the principles employed; of the interactions among people at all levels.

Particularly important in this pyramid of causality is the accumulated scientific and technical knowledge. It is contained within engineering itself, but also within universities, learned

[173] Brian Arthur focuses on this in *The Structure of Invention* (Arthur 2007). Schumpeter divided technological change into three phases: invention (the creation of new technologies); innovation (the commercial introduction of new technologies); and diffusion (the spreading of new technologies). Arthur noted that of these, invention has been by far the least studied and set out to remedy this in his paper. Like the other processes of technological change, invention raises its own challenges and problems, the solution of which may raise further challenges. As a result, invention is a recursive process: it repeats until each challenge or hierarchy of problems resolves itself into one that can be physically dealt with. It is a challenging process, usually lengthy, part-conceptual and part-experimental. It also typically involves many people and processes, so it is becoming difficult or impossible to name an individual originator of many modern inventions.

societies, national academies of science and engineering, and published journals. These form the critical substrate from which technologies emerge. Importantly, the logical structure for invention extends to origination in science; without the accumulated knowledge and capacity to innovate in science, the basis for technology would be vastly poorer.

Typically the initial version of a novel technology is crude and must be made reliable, scaled up and applied effectively to different purposes. As a technology develops, it runs into barriers and bottlenecks that are usually overcome by *replacing* the impeded components with more efficient components. This again leads to requirements to adjust other parts to accommodate it – it may even require a rethink of the architecture of the technology.

In addition to internal replacement, another mechanism of development is at work, which Arthur calls *structural deepening*. Here the component presenting an obstacle is retained, but additional components and assemblies are added to it to work around the limitation. By adding subsystems, technologies add "depth" and design sophistication to their structures as well as complexity.

The two mechanisms of development, internal replacement and structural deepening, apply through the life of a technology. Early on, a new technology is developed deliberately and experimentally. Later, it develops further as new instances of it are designed for specific purposes – it becomes part of the standard engineering process. But eventually there comes a time when neither component replacement nor structural deepening add much to performance. The technology reaches maturity. In the absence of a suitable novel principle, the old one gets *locked in.*

The locking-in of an older successful principle causes *adaptive stretch*. But at some point of development, the old principle cannot be stretched further. The way is now open for a novel principle to get a footing. The origination of a new principle, structural deepening, lock-in, and adaptive stretch, therefore have a natural cycle. Eventually the old principle is strained beyond its limits and gives way to the new one. The new base principle is simpler, but in due course it may become entangled itself.

### THE DEVELOPMENT OF NEW DOMAINS

Many domains coalesce around a central technology. Computation spawned supporting technologies which might themselves develop into separate domains: printers, punched card readers, external memory systems, and programming languages. Other domains form around families of phenomena and the understandings and practices that go with these. Electronics and radio engineering were built on the understanding of electrons and electromagnetic waves.

A nascent field starts as part of its parent domain. Genetic engineering in its medical applications began as a minor offshoot of molecular biology and biochemistry. There is an experimental feeling about these early days; participants see themselves as solving particular problems in their parent domain. But in time, the new cluster acquires its own vocabulary and way of thinking.

Eventually domains reach old age. Some perish, but most live on: we still use bridges and roads, sewer systems and electric lighting, much as we did 100 years ago (though individual technologies within the domain develop, sometimes quite considerably like electric lighting over the past few years), but we still tend to take them for granted as technologies.

Not all domains go through a cycle of youth, adulthood and old age. Some disrupt the cycle by reinventing themselves every few years. They *morph* when one of its key technologies undergo radical change. Electronics changed character when the transistor replaced the vacuum tube. The communications and information technology domains keep morphing.

Besides morphing, a domain evolves new domains, often with multiple parentage. Information technology including the Internet is a child of telecommunications and computation, resulting from the marriage of high-speed data transmission and high-speed data manipulation. The parent fields live on, but they have birthed things that exist on their own, and now a good deal of their energy flows to the new branch. This tendency to morph and to sire new domains is part of what gives bodies of technology a living quality.

The economy adjusts when it encounters a novel body of technology. A new domain is described by its methods, devices, understandings, and practices. A particular industry consists of its organizations and business processes, production methods and physical equipment, all widely defined as "technologies". These two collections of individual technologies – one from the new domain, and the other from the particular industry – come together and influence one another, resulting in other new combinations.

### IT ALL TAKES TIME

The unfolding of the new technology and readjusting of the economy takes a great deal of time. A revolution will eventually happen when the businesses and commercial procedures of the economy are arranged around its technologies, and these technologies adapt and become competitive on general compatibility and costs with other technologies that deliver similar benefits.

For this to happen, the new domain must gather adherents and prestige, find purpose and uses, resolve obstacles and fill gaps in its components, and develop technologies that support it and bridge it to the technologies that use it. Markets must be found, and the existing structures of the economy must be adjusted to make use of the new domain. The new domain must be recognized and the engineers who command the grammar of the old need to retool themselves for the new. All this must be mediated by finance, institutions, management, and government policies, and by developing skills for the new domain.

Domains therefore evolve differently from individual technologies. Once invented, the commercial development of a jet engine is basically focused, concentrated, and rational. Domains emerge slowly around loosely understood phenomena or novel technology, and build organically on the components, practices, and understandings that support these. As a new domain arrives, the economy encounters it and alters itself as a result.

"There is no reason that such evolution, once in motion, should end." (p 181)[174] But the process may take decades.

[174] Arthur and Polak (2006) demonstrated technological evolution based on a simple computer model, in which the elements are common logic functions. Starting from a primitive technology, new circuits representing new

## ENDNOTE: ARTHUR'S THREE LAWS

The Edge World Question Center[175] asks a different question each year which elicits 150-200 responses from prominent people with a wide range of skills and experiences. In 2004 it was "What's your law?" W. Brian Arthur came up with three "laws" which form an interesting background to his work on technology and provides an additional perspective on the future (Arthur 2004). Their subject matter figures in *The Nature of Technology*, though the treatment in the book doesn't immediately convey an impression that it should be elevated to the status of "laws". The prompt the question gave Arthur in 2004 to come up with some basic principles has therefore proved very useful.

Arthur's response is quoted verbatim.

**Arthur's First Law**: *High-tech markets are dominated 70-80% by a single player – product, company, or country.* The reason: Such markets are subject to increasing returns or self-reinforcing mechanisms.[176] Therefore an initial advantage – often bestowed by chance – leads to increasing advantage and eventually heavy market domination. (Absent government intervention, of course).

**Arthur's Second Law**: *As technology advances it becomes ever more biological.* We are leaving an age of mechanistic, fixed-design technologies, and entering an age of metabolic, self-reorganizing technologies. In this sense, as technology becomes more advanced it becomes more organic—therefore more "biological." Further, as biological mechanisms at the cellular and DNA levels become better understood, they become harnessed and co-opted as technologies. In this century, biology and technology will therefore intertwine.

**Arthur's Third Law**: *The modularization of technologies increases with the extent of the market.* Just as it pays to create a specialized worker if there is sufficient volume of throughput to occupy that specialty, it pays to create a standard prefabricated assembly, or module, if its function recurs in many instances. Modularity therefore is to a technological economy what the division of labor is to a manufacturing one—it increases as the economy expands.

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technologies are constructed by randomly wiring together existing ones and testing the result to see whether they satisfy any existing needs. If a circuit proves useful – satisfies some need better than its competitors – it replaces the one that previously satisfied that need. In the computer model it then adds itself to the active collection of technologies and becomes available as an element for the construction of still further circuits. So elements constantly add to the set of active technologies as they find uses, and leave again if rendered obsolete by others. In this way the collection of technologies bootstraps upwards by first creating simple technologies that satisfy simple needs, then from these more complex technologies to new ones that satisfy more sophisticated needs.

In several 250,000-step runs, the system evolved an 8-bit code, the basis of a simple calculator. Arthur (2009a, p 184) says that this would be impossible (one might say equivalent to the legendary monkey typing Shakespeare's plays by randomly hammering the keyboard) without the model creating a series of stepping-stone technologies first, which were then used as building blocks to create circuits of intermediate complexity to be finally used to create more complicated circuits. Arthur and Polak found that if they took away the intermediate mechanisms that called for these stepping-stone technologies, the complex needs went unfulfilled.

[175] http://www.edge.org/questioncenter.html.

[176] See the section on the Santa Fe Institute in Appendix 5 on his development of dynamic models involving positive feedback from technological change (Arthur 1989, 1990).

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