CHANGING GLOBAL SCENARIOS

By Hans Hoegh-Guldberg

BACKGROUND PAPER 1

CLIMATE CHANGE AND THE FLORIDA KEYS

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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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 21st 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 21st century. The concluding sections of this background paper 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 paper, 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 (Hoegh-Guldberg 2010)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 background paper.

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.

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[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 paper, Hoegh-Guldberg (2010b) for the first time quantifies the possible collapse in the global economic product under conditions of severe climate change, Hoegh-Guldberg (2010c) describes the "new" economics that may influence macroeconomic and financial policy including the impact of climate change itself, and Hoegh-Guldberg (2010d) 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 (Hoegh-Guldberg 2010d) 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.

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[2] This assumption is taken up in Hoegh-Guldberg (2010b), 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.

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:

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 20th 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

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 21st century that would *very likely* be larger than those observed during the 20th 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 21st 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 21st 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 21st 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

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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).

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 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 background paper):

- 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 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

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[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 "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).

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 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):

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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.

"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 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:

“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]

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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).

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 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 21st 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,

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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.

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 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)

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[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 background paper, 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).

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 stabilization path will eventually exceed $2^{O}C$. A 550 ppm carbon-equivalent path (CO_2e) 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_2e 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 $2.0\text{-}2.4^{0}C$, and will require a peak year for emissions by 2015. Stabilizing at 490-535 ppm CO_2e will require 30-60% lower emissions by 2050, resulting in a $2.4\text{-}2.8^{0}C$ increase in global temperature. Emissions will need to peak by 2020 for this to happen. (p 67)

Stabilization paths at 445-535 ppm CO_2e 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_2e 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)

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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 Hoegh-Guldberg (2010b), dealing with limits to growth under global warming.

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 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_2e 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

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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 5.5^0C, 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) 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 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

[22] The workshop included Mark Lynas, who has written about the Stockholm Institute project (Lynas 2008b).

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)

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 Hoegh-Guldberg 2010c, "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:

[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.

- The incoming US president, not yet identified when the report was written, is crucial as nothing substantial will be agreed upon without the US.
- 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

[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).

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.

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 2^0C 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 Hoegh-Guldberg (2010c), 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.

[25] http://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/dir_global_scenarios_07112006.html.

- 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.
- 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 Hoegh-Guldberg (2010c). 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."

[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.

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, ρ (rho)) and (2) between individuals regardless of when they appear on the scene ('eta', η). He agreed with 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, ρ, and the elasticity of the social benefits attained (social marginal utility, η). 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)

[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, η is the elasticity of the social benefits attained (also called the social marginal utility), g is per-capita consumption growth rate, and ρ 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. Hoegh-Guldberg (2010c) discusses how a new economic paradigm may be coming into focus.

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?

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_2e). The current level is 430 ppm CO_2e 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_2e 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.

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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).

Cuts in non-energy emissions, such as those resulting from deforestation and from agricultural and industrial processes, are also essential.

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 2^0C. In the longer term, there would be more than a 50% chance that the temperature rise would exceed 5^0C. 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_2e, perhaps 4 or more, over the next century. That is likely to take us to around, or well beyond, 750 ppm CO_2e 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 5^0C. 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 5^0C 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 5^0C 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 3–4^0C, or the decreasing absorptive capacity of the oceans. Further, a thawing of the permafrost is likely to result in strong methane release.

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[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.

- 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) 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.

[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.

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 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.

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[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 Hoegh-Guldberg (2010c) 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.

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 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.

[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 Hoegh-Guldberg (2010d), section on technologies and technology policy.

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.

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 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.

[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).

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.

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.

[34] http://www.grameenfoundation.org/. See further Hoegh-Guldberg (2010d) on technology, in particular the section (towards the end) on implications for the world's least developed societies

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 background paper 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.

[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) .

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."

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

[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."

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.

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)

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

[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.

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

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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."

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."

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]

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

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[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).

[41] The realism, or otherwise, of geoengineering technologies is discussed in Hoegh-Guldberg (2010d).

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 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 a background paper 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]

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 Hoegh-Guldberg (2010c), 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 paper: "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.

[42] http://www.350.org/.

- 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.
- 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).

[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)

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 background paper 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 calcium carbonate, calcite.

The paper highlights three issues of particular importance for the future of coral reefs:

[44] http://www.abc.net.au/catalyst/stories/s2029333.htm.

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)

   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 Hoegh-Guldberg 2010d) 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."

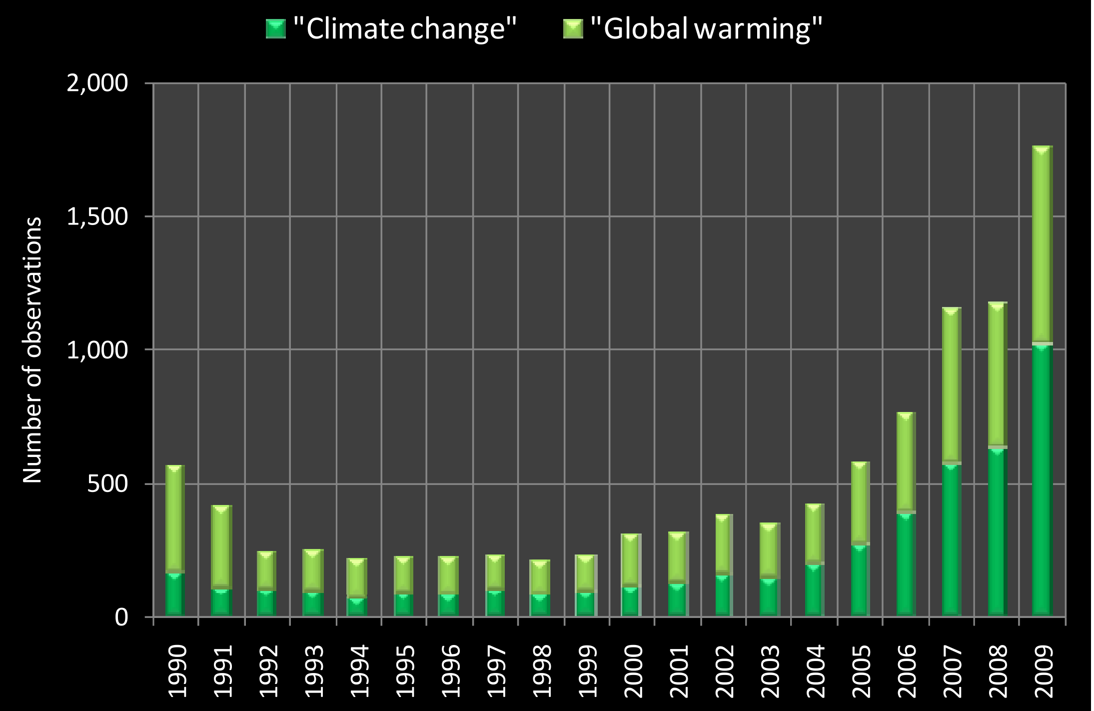
Business-as-usual: "As custodians of geological history, reefs offer both immense geological evidence and stark recent testimony to the potentially catastrophic effects of destabilizing global climate. Although, being carbonate platforms, they are particularly sensitive to disruptions of the carbon cycle, 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*



Source: http://www.newscientist.com, June 26, 2010

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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