Is It Too Late to Prevent Catastrophic Climate Change?

Lecture to a Meeting of the Royal Society of the Arts

Sydney, 21 October 2009

Clive Hamilton[1]

Alarm bells

This paper lays out the latest scientific understanding of the task humanity faces to avoid catastrophic climate change.[2] One of the most striking features of the global warming debate has been how, with each advance in climate science, the news keeps getting worse. Although temporarily slowed by the effects of the 2008 global financial crisis, the world's greenhouse-gas emissions have been growing much faster than predicted in the 1990s. In addition, since 2005 a number of scientific papers have described the likelihood of the climate system passing significant 'tipping points'—small perturbations that cause large changes—beyond which the warming process is reinforced by positive feedback mechanisms.[3]

The paleoclimate record shows the Earth's climate often changing abruptly, flipping from one state to another, sometimes within a few years.[4] It now seems almost certain that, if it has not occurred already, within the next several years enough warming will be locked in to the system to set in train feedback processes that will overwhelm any attempts we make to cut back on our carbon emissions. We will be powerless to stop the jump to a new climate on Earth, one much less sympathetic to life.

---

[1] Charles Sturt Professor of Public Ethics, Centre for Applied Philosophy and Public Ethics at the Australian National University (clive.hamilton@anu.edu.au).
[2] It is adapted from Chapter 1 of my forthcoming book, *Requiem for a Species*. For reviewing the chapter I am very grateful to Alice Bows of the Tyndall Centre for Climate Change Research, Andrew Glikson of the Australian National University, Graeme Pearman of Monash University and Mike Raupach of the CSIRO.
[3] For example, Tim Lenton et al., 'Tipping elements in the Earth's climate system', *Proceedings of the National Academy of the Sciences*, vol. 105, no. 6, 12 February 2008.
[4] Jørgen Peder Steffensen et al., 'High-Resolution Greenland Ice Core Data Show Abrupt Climate Change Happens in Few Years', *Science*, vol. 321, no. 5889, 1 August 2008. Graeme Pearman notes that these abrupt changes may have been due to rapid deglaciation coming out of the last ice age, 'a process that would not be applicable to Earth which is already substantially more deglaciated' (pers. comm.).

The accelerating rate of melting of the Arctic Sea ice has shocked the scientists studying it, with many believing that summer ice will disappear entirely within the next decade or two. Some expect it to be gone even sooner.[5] Mark Serreze, director of the US National Snow and Ice Data Center, has declared that 'Arctic ice is in its death spiral'.[6] The dark water surface that will replace the reflective white one in summer will absorb more solar radiation setting off a positive feedback process of further warming. This is expected to initiate a cascade of effects as the patch of warmth over the Arctic spreads in all directions, warming the surrounding oceans, melting the Siberian permafrost and destabilising the Greenland ice-sheet.

In December 2007 after a summer that saw a dramatic decline in Arctic sea ice, NASA climate scientist Jay Zwally said: 'The Arctic is often cited as the canary in the coal mine for climate warming. Now, as a sign of climate warming, the canary has died. It is time to start getting out of the coal mines.'[7] Another resorted to a Biblical metaphor: 'Climate scientists have begun to feel like a bunch of Noahs'.[8] The world's top climate scientists are now ringing the alarm bell at a deafening volume because the time to act has virtually passed, yet it is as if the frequency of the chime is beyond the threshold of human hearing.

At the same time as the science is becoming more worrying, growth of the world's greenhouse gases emissions has been accelerating. In the 1970s and 1980s global emissions of carbon dioxide (CO_2) from burning fossil fuels increased at 2 per cent each year. In the 1990s they fell to 1 per cent. Since the year 2000, the growth rate of world's CO_2 emissions has almost trebled to 3 per cent a year.[9] At that rate annual emissions will double every 25 years.

While rates of growth in rich countries have fallen below 1 per cent, they have expanded enormously in developing countries, led by China where fossil-fuel

[5] Others, such as the UK Met Office's Vicki Pope, believe the recent sharp decline could be due to natural variation but that over the longer term human-induced warming will lead to the disappearance of Arctic sea-ice in the summer. Vicki Pope, 'Scientists must rein in misleading climate change claims', *The Guardian*, 11 February 2009.
[6] Quoted in Deborah Zabarenko, 'Arctic ice second-lowest ever; polar bears affected', *Reuters*, 27 August 2008
[7] Quoted in the *New York Sun*, 22 December 2007
[8] Andrew Weaver of the University of Victoria in British Columbia quoted by Richard Monastersky, 'A Burden Beyond Bearing', *Nature*, vol. 458, 30 April 2009, p. 1094
[9] Ross Garnaut, *The Garnaut Climate Change Review*, Cambridge University Press, Melbourne, 2008, Table 3.1 p. 56

emissions have grown by 11-12 per cent annually in the first decade of this century.[10] By 2005 China accounted for 18 per cent of the world's greenhouse gas emissions; by 2030 it is expected to be responsible for 33 per cent.[11] The Chinese government takes climate change seriously — much more than the United States under the Bush Administration and arguably more than the Obama Administration— and has implemented a number of policies designed to cut the emissions intensity of electricity and transport, but the sheer expansion of the economy is swamping all attempts at constraining the growth of carbon pollution.

Rather than decarbonising, the world is carbonising at an unprecedented rate, and it is doing so at precisely the time we know we have to stop it.

The recession that arrived in late 2008 slowed, and in some countries reversed, growth in annual carbon emissions, but the volume of greenhouse gases in the atmosphere has continued to rise,[12] just as reducing the flow rate of tap water does not stop the bath filling up. Even if annual emissions stopped dead, the fact that most of past carbon emissions remain in the atmosphere for a long time would mean that the elevated global temperature would persist for many centuries.[13]

Worse than the worst-case

In the 1990s the IPCC developed a number of scenarios to reflect future influences on emissions and associated warming. Of the half-dozen or so main IPCC scenarios, the 'worst-case scenario' is known as A1FI. This scenario, the one that has given the highest estimates of warming in the IPCC reports, assumes strong rates of global economic growth with continued high dependency on fossil-fuel based forms of energy production over the next decades.

In the mid-2000s it began to become clear that growth in global emissions had risen so high that the world has shifted onto a path that is worse than the worst-case scenario imagined by the IPCC. In its worst case the IPCC anticipated growth in CO_2

[10] Garnaut, *The Garnaut Climate Change Review*, p. 66
[11] Garnaut, *The Garnaut Climate Change Review,* Table 3.2, p. 65. In which year, the US is expected to account for 11 per cent (down from 18) and India 8 per cent (up from 4.6 per cent).
[12] National Oceanic and Atmospheric Administration, 'Trends in Atmospheric Carbon Dioxide - Mauna Loa', http://www.esrl.noaa.gov/gmd/ccgg/trends/
[13] Susan Solomon, Gian-Kasper Plattner, Reto Knutti and Pierre Friedlingstein, 'Irreversible climate change due to carbon dioxide emissions', *Proceedings of the National Academy of Sciences*, vol. 106, no. 6, 10 February 2009

emissions of 2.5 per cent per annum through to 2030, yet we have seen that from around 2000 global emissions began growing at around three per cent a year.[14] This worse-than-the-worst case scenario should now be regarded as the most likely one in the absence of determined intervention.[15]

It is not only the dramatic increase in the growth rate of global emissions that is turning alarm into panic; advances in climate science have made the future appear more grim than we imagined. In particular, anthropogenic warming is likely to disrupt the natural carbon cycle. This is not place to describe the carbon cycle in any detail,[16] except to note that when we dig up and burn coal over half of the CO_2 released is absorbed by land and ocean sinks. The rest stays in the atmosphere, some of it for a very long time. A quarter will still be affecting the climate after a thousand years and around 10 per cent after a hundred thousand years.

Through global warming, changes in atmospheric carbon alter the rate of absorption and release of carbon from natural sinks in the oceans and land. Climate-carbon cycle feedback mechanisms include the reduced ability of warmer ocean waters to remove CO_2 from the atmosphere, and the decline in deep-ocean mixing and thus the transport of carbon into the deep ocean from the carbon-rich surface layer. In addition, warming is expected to cause more deforestation through droughts, fires and high temperatures inhibiting plant growth.

When ocean and land sinks take up less carbon, a greater proportion of the CO_2 put into the atmosphere by humans stays there, strengthening feedback effects and causing more warming. Perhaps most worrying, the threshold for release of methane and CO_2 from the vast permafrost of Siberia is approaching, driven by temperature rise in the Arctic which at nearly 4°C is three to four times the global average.

---

[14] See also Katherine Richardson et al., *Synthesis Report*, from the Climate Change: Global Risks, Challenges & Decisions conference, University of Copenhagen, Copenhagen, 2009, Box 2.

[15] Recent observed climate trends are compared to the model projections contained in the 2001 IPCC report by S. Rahmstorf, A. Cazenave, J. A. Church, J. E. Hansen, R. F. Keeling, D. E. Parker and R. J. C. Somerville, 'Recent climate observations compared to projections', *Science*, vol. 316, no. 5825, 2007.

[16] See J. G. Canadell et al., 'Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks', *Proceedings of the National Academy of Sciences*, vol. 104, pp. 18866-70, 2007; M. R. Raupach, J. G. Canadell and C. Le Quéré, 'Anthropogenic and biophysical contributions to increasing atmospheric CO_2 growth rate and airborne fraction', *Biogeosciences*, vol. 5, pp. 1601-13, 2008

Overall, the effectiveness of natural sinks at removing carbon dioxide from the atmosphere has declined by five per cent over the last 50 years, and the decline will continue.[17] The presence of climate-carbon cycle feedbacks means we must reduce our direct emissions by more than we would need to if we had to contend only with direct effects. The IPCC estimates that, in order to stabilise greenhouse gas concentrations in the atmosphere at 450 parts per million, the presence of carbon cycle feedbacks means that we will have to reduce our total emissions over the twenty-first century by 27 per cent *more* than we would otherwise.[18]

Scientific urgency *versus* political sclerosis

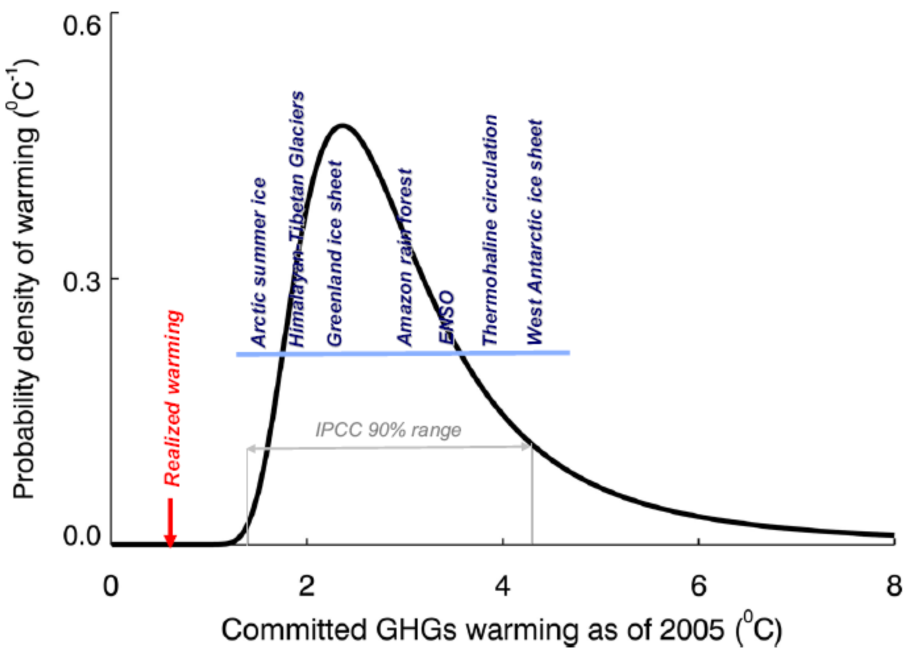
Most leading climate scientists now believe that 2°C of warming would pose a substantial risk both because of its direct impacts on climatically sensitive Earth systems and because of the potential to trigger irreversible changes in those systems. The latter include the disappearance of Arctic summer sea-ice, the melting of the Himalayan-Tibetan glaciers and the melting of much of the Greenland ice-sheet.[19] The relationship between the amount of warming and certain climate tipping points is shown in Figure 1. Note that the authors estimate that, as at 2005, the Earth was already committed to 2.4°C of warming above the pre-industrial level, irrespective of any actions we now take.[20] Even so, James Hansen has declared the goal of keeping warming at 2°C 'a recipe for global disaster'.[21] He believes the safe level of CO_2 in the atmosphere is no more than 350 ppm. The current level of CO_2 is 385 ppm, rising at around 2 ppm each year, so that we have already overshot our target and must somehow draw down large volumes of CO_2 from the atmosphere.[22]

Despite these serious doubts, is aiming to limit warming to even 2°C a feasible goal? What do we have to do to stop emissions pushing temperatures above this level? Just

[17] Global Carbon Project, 'Carbon budget and trends 2007', www.globalcarbonproject.org, 26 September 2008
[18] IPCC, *Climate Change 2007: Synthesis Report*, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, R. K. Pachauri and A. Reisinger (eds), IPCC, Geneva, 2007, p. 67
[19] Lenton, et al., 'Tipping elements in the Earth's climate system', Table 1
[20] V. Ramanathan and Y. Feng, 'On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead', *Proceedings of the National Academy of Sciences*, vol. 105, no. 38, 23 September 2008
[21] James Hansen, 'Global Warming Twenty Years Later: Tipping Points Near', Speech to the National Press Club, Washington, 23 June 2008
[22] Richardson et al., *Synthesis Report*, p. 18

before the Bali climate change conference at the end of 2008 climate scientists released a new assessment arguing that in order to have a good chance of avoiding the 2°C threshold rich countries must by 2020 reduce their greenhouse-gas emissions by 25-40 per cent below 1990 levels.[23] The 25 per cent target quickly became entrenched internationally as the benchmark against which the commitment of rich countries is judged. The fact that aiming for 25 per cent instead of 40 per cent means developing countries will have to do a lot more was conveniently passed over.

Figure 1 Tipping points associated with various degrees of warming, and probability distribution around estimated warming already committed to (2.4°C)



Source: Ramanathan & Feng (2008)

We have seen that rather than declining, or even growing more slowly, global emissions have been accelerating over the last decade. To have any hope of avoiding catastrophe, global emissions must peak within the next few years, and certainly no later than 2020, then begin a rapid decline to the point where all energy generation and industrial processes are completely carbon free. Hansen has put it bluntly:

> Decision-makers do not appreciate the gravity of the situation. … Continued growth of greenhouse gas emissions, for just another decade, practically

[23] See, e.g., Bill Hare, Michiel Schaeffer and Malte Meinshausen, ‘Emission reductions by the USA in 2020 and the risk of exceeding 2°C warming’, *Climate Analytics*, March 2009.

> eliminates the possibility of near-term return of atmospheric composition beneath the tipping level for catastrophic effects.[24]

Meeting in March 2009 the world's leading climate scientists reached a similar conclusion: 'immediate and dramatic emission reductions of all greenhouse gases are needed if the 2°C guardrail is to be respected'.[25]

The urgent question we must now ask ourselves is whether the global community is capable of cutting emissions at the speed required to avoid the Earth passing a point of no return beyond which the future will be out of our hands. It is this irreversibility that makes global warming not simply unique among environmental problems, but unique among all of the problems humanity has faced. Beyond a certain point it will not be possible to change our behaviour to control climate change no matter how resolved we are to do so.

If global emissions must reach a peak within 5-10 years then decline rapidly until the world's energy systems are all but decarbonised, are the institutions of government in the major nations of the world capable of responding in time? Are international institutions capable of agreeing on a global plan adequate to the task? These are questions on which climate scientists have little useful to say; they are in the domain of political and behavioural scientists. However, confidence in the ability of humans to respond with the required urgency is dashed when we understand fully how near we are to the point of no return.

The carbon budget

Climate scientists have recently adopted the so-called budget approach to describe the task before us. Because CO_2 persists in the atmosphere for a very long time,[26] it is cumulative emissions that matter, so that the total amount of carbon emissions humans put into the atmosphere over the next decades will determine our fate. A tonne of carbon emitted today counts as much as one emitted in 2050, so setting targets such as an 80 per cent cut in emissions by 2050, which could be attained by any number of emissions trajectories, is misleading and potentially dangerous.

---

[24] Hansen et al., 'Target Atmospheric CO_2: Where Should Humanity Aim?'
[25] Richardson et al., *Synthesis Report*, p. 18
[26] Solomon et al., 'Irreversible climate change due to carbon dioxide emissions'

In a paper to a meeting of the Royal Society in 2008, Kevin Anderson and Alice Bows from the United Kingdom's Tyndall Centre for Climate Change Research (one of the top such centres) use the budget approach to set out the situation in the most striking way.[27] There are two ways of thinking about the task. First, we can set a particular target, such as stabilisation at 450 ppm, and calculate how soon global emissions must peak and how quickly they must fall thereafter to meet it. Then we must ask whether the path so defined is politically possible given the national and international institutions that must decide on and implement the plan.

Alternatively, we can make the most hopeful judgment about the emissions reduction path the world is likely to follow then ask how much warming it will entail. Anderson and Bows analyse the task both ways, but here I will focus on the second approach. In other words, we will make some optimistic assumptions about how soon and how quickly emissions can be reduced over the century and see what sort of world we would be left with.[28]

There are three broad types of activity that determine the volume of greenhouse gases that go into the atmosphere: emissions of CO_2 from burning fossil fuels for energy and in industrial processes; CO_2 emissions from cutting and burning forested areas; and emissions of greenhouse gases other than CO_2. Anderson and Bows first make some simple but plausible estimates of what we can expect from the second and third of these. Having made these estimates we can then concentrate on the big one, CO_2 emissions from fossil fuels.

Deforestation currently accounts for 12-25 per cent of the world's annual anthropogenic or human-induced CO_2 emissions.[29] Reducing deforestation will need to be a major focus of efforts to minimise climate change. If the world's decision-makers adopt a resolute attitude to tackling climate change then an optimistic assessment would see deforestation rates peak in 2015 and fall rapidly thereafter, to around half their current levels by 2040 and close to zero by 2060.

---

[27] Kevin Anderson and Alice Bows, 'Reframing the climate change challenge in light of post-2000 emission trends', *Philosophical Transactions of the Royal Society*, The Royal Society, 2008
[28] All figures below are taken from the analysis by Anderson and Bows.
[29] Anderson and Bows, 'Reframing the climate change challenge', p. 5

If this happens then the total stock of carbon dioxide locked up in the world's forests will fall from 1060 billion tonnes in the year 2000 to around 847 billion tonnes in 2100, a decline of 20 per cent.[30] Over this century, then, deforestation would add 'only' 213 billion tonnes of CO_2 to the atmosphere. (A less optimistic scenario would see deforestation add 319 billion tonnes of CO_2 to the atmosphere.)

What about non-CO_2 greenhouse gases? Methane and nitrous oxide are the two main non-CO_2 greenhouse gases. In 2000 they accounted for about 23 per cent of the global warming effect of all greenhouse gas emissions.[31] They are mostly emitted from agriculture—methane from livestock and rice cultivation and nitrous oxide from the use of fertilisers. Emissions from agriculture are growing rapidly as more land is turned over to crops and pasture, and diets shift to more meat as people in countries like China become better off. Population growth will make the task of reducing non-CO_2 emissions harder because food is the first item of consumption humans must have. Like emissions from deforestation, agricultural emissions must peak soon then decline. Unlike emissions from deforestation, they cannot be reduced to zero because of the nature of food production.

If the world's leaders take resolute action, an optimistic assumption would be that non-CO_2 emissions will continue to rise until 2020, up from 9.5 billion tonnes annually (measured in CO_2-e) in 2000 to 12.2 billion tonnes, then fall to 7.5 billion tonnes by 2050, the level at which it stabilises.[32] If, as expected, world population increases to a little over nine billion by the middle of the century, these 7.5 billion tonnes of CO_2-e allocated to food production must be spread across an additional 2.6 billion people,[33] which means that the emissions intensity of food production must be approximately halved over the next four decades.

---

[30] A billion tonnes is also called a gigatonne (Gt). It is organic carbon rather than CO_2 that is locked up in forests, but the analysis here expresses it in terms of the CO_2 that results from oxidizing the carbon through burning or decay.

[31] Anderson and Bows, 'Reframing the climate change challenge', p. 7. After rising for many years, in 1999 global methane emissions plateaued. They began to rise again in 2007, possibly due to the melting of the Siberian permafrost. See M. Rigby et al., 'Renewed growth of atmospheric methane', *Geophysical Research Letters*, vol. 35, L22805, 2008.

[32] Anderson and Bows, 'Reframing the climate change challenge', pp. 8-9

[33] In 2007 the world's population was 6.6 billion and the UN's middle estimate for 2050 is 9.2 billion (United Nations, *World Population Prospects: The 2006 Revision*, UN Department of Economic and Social Affairs, New York, 2007).

Putting together these optimistic scenarios for deforestation and non-CO_2 greenhouse gas emissions, Anderson and Bows calculate that the total cumulative emissions from these sectors over this century will amount to just under 1100 billion tonnes CO_2-e emitted into the atmosphere. This provides the floor on which can be constructed emission scenarios for energy and industrial CO_2 emissions, the main game in tackling climate change.

Two parameters are critical—the date at which global emissions reach their peak and the rate at which emissions fall thereafter. These will determine the total amount of greenhouse gases that go into the atmosphere over this century, the resulting increased concentration of greenhouse gases, and the global temperature increase that follows. The later the peak, the more quickly emissions must fall to keep within an emissions budget.

A very optimistic assumption is that global emissions will peak in 2020.[34] Stopping global emissions growth will require that from that year any increase in emissions from developing countries must be more than offset by a decline in emissions from developed countries. An optimistic assessment of the prospects for an agreement at Copenhagen could see emissions peak in 2020, although a more realistic date would be 2030.

Nevertheless, if we assume that overall emissions growth can be halted in 2020, what rate of emissions reduction would be feasible in each year thereafter?

The Stern Review includes a short but vitally important section that provides some precedents.[35] Economic collapse in the Soviet Union after the fall of the Berlin Wall in 1989 led to a decline in its greenhouse gas emissions of 5.2 per cent each year for a decade. During this period economic activity more than halved[36] and widespread social misery ensued.

When France embarked on an aggressive program of building nuclear capacity—a 40-fold increase in 25 years from the late 1970s—annual emissions from the electricity

---

[34] It is, for example, the most optimistic outcome modeled by Hare et al., 'Emission reductions by the USA in 2020 and the risk of exceeding 2°C warming'.
[35] Nicholas Stern, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge, 2007, Box 8.3, p. 231. Anderson and Bows also draw from it.
[36] See the World Bank figures reported by the BBC http://news.bbc.co.uk/2/shared/spl/hi/guides/457000/457038/html/default.stm

and heat sector fell by 6 per cent, but total fossil emissions declined by only 0.6 per cent annually.

In the 1990s, the ‘dash for gas’ in Britain saw a large substitution of natural gas for coal in electricity generation. Total greenhouse gas emissions fell by 1 per cent each year in the decade. Depressingly, Stern concluded that reductions in emissions of more than 1 per cent over an extended period ‘have historically been associated only with economic recession or upheaval’.[37]

Given that some world leaders recognise the severity of the threat posed by global warming and the need, unprecedented except in wartime, for a rapid structural change in their economies, it might be reasonable—if optimistic—to expect that the world could agree to reduce emissions by 3 per cent per annum after the 2020 peak until they reach the floor of 7.5 billion tonnes CO_2-e set by the need to feed the world. Anderson and Bows show that because of the assumptions about rates of decline of emissions from deforestation and food production, the 3 per cent rate of decline of emissions overall will require a 3.5-4 per cent rate of decline in CO_2 emissions from energy and industrial processes.[38]

Since emissions in developing countries would be expected to continue growing, although at a slower rate, for some time after 2020 before peaking and beginning to fall, emission reductions in rich countries will need to be much higher than 3-4 per cent, perhaps 6-7 per cent, a level higher than that associated with Russia’s economic collapse in the 1990s.

It is hard to imagine even the most concerned and active government—Sweden’s perhaps—introducing policies that would bring about such a rapid industrial restructuring. Nevertheless, let us put ourselves in the most optimistic frame of mind we can. If global emissions do peak in 2020 then decline by 3 per cent each year, with energy emissions in rich countries falling by 6-7 per cent, could we head off the worst effects of climate change, or even keep it to ‘safe’ levels?

The answer provided by Anderson and Bows, and backed by other analyses, is a very grim one indeed. If that is the path taken by the world then over the century we will

[37] Stern, *The Economics of Climate Change*, p. 232
[38] Anderson and Bows, ‘Reframing the climate change challenge’, Table 7, p. 14

pump out an extra 3,000 billion tonnes of greenhouse gases,[39] which would not see atmospheric concentrations of greenhouse gases stabilise at the 'safe' level of 450 ppm. Nor would they stabilise at the very dangerous level of 550 ppm. They would in fact rise to 650 ppm!

Can this be true?

Table 1 shows the calculus of Anderson and Bows in its starkest form. Their analysis has been replicated, with small variations, by other groups.[40] A recent report by the German Advisory Council on Global Change (WGBU) assessed what it would take to have a good chance of remaining within the 2ºC guardrail.[41] To have a two out of three chance of limiting warming to 2ºC, cumulative global emissions over the next forty years would need to be kept below 750 billion tonnes (or gigatonnes, Gt), with a small residual amount each year beyond 2050. Of course, the first task is to reverse the trend of rising emissions. The relationship between the peaking year and subsequent rates of emissions reductions is shown in Figure 2.

Table 1 Peaking year, annual reduction rates and associated warming

Peaking year	Annual reduction rate for all emissions	Annual reduction rate for energy and industrial emissions	Resulting concentration (ppm CO_2-e)	Likely associated warming
2015	4%	6.5%	450 ppm	2ºC
2020	6%	9%	550 ppm	3ºC
2020	3%	3.5%	650 ppm	4ºC

Source: Anderson and Bows (2008), p. 17

[39] Anderson and Bows, 'Reframing the climate change challenge', p. 13
[40] One study concluded that to keep warming from exceeding 2°C total anthropogenic emissions must be limited to 3,670 billion tonnes of CO_2 (ignoring non-CO_2 forcing agents). Half of this amount has already been emitted since the start of the Industrial Revolution in the eighteenth century, leaving a budget of 1,850 billion tonnes for the twenty-first century, or 1,460 billion tonnes if non-CO_2 forcings are taken into account (Myles Allen et al., 'Warming caused by cumulative carbon emissions towards the trillionth tonne', *Nature*, vol. 458, 30 April 2009). Anderson and Bows' analysis shows that, if global emissions peak in 2020 and fall by 3 per cent per annum thereafter, an additional 3,000 billion tonnes of CO_2-e will be added to the atmosphere, 60 per cent more than allowed by the 2°C target.
[41] German Advisory Council on Global Change (WGBU), *Solving the Climate Dilemma: The Budget Approach,* WGBU, Berlin, 2009

The WGBU study concluded that even a delay in the peaking year to 2015 means that global emissions must fall at a rate close to 5 per cent per annum—the entire Kyoto commitment in one year, for many years. Any further delay makes the target impossible.

> Delaying the peak year even further to 2020 could necessitate global emissions reduction rates of up to 9% per year – i.e. reductions on an almost inconceivable scale, entailing technological feats and social sacrifices on a scale comparable to those of the Allied mobilization during the Second World War.[42]

John Schellnhuber, head of the Potsdam Institute for Climate Impact Research and lead author of the WGBU report, referred to the areas under the curves that describe carbon budgets as 'vicious integrals'.[43]

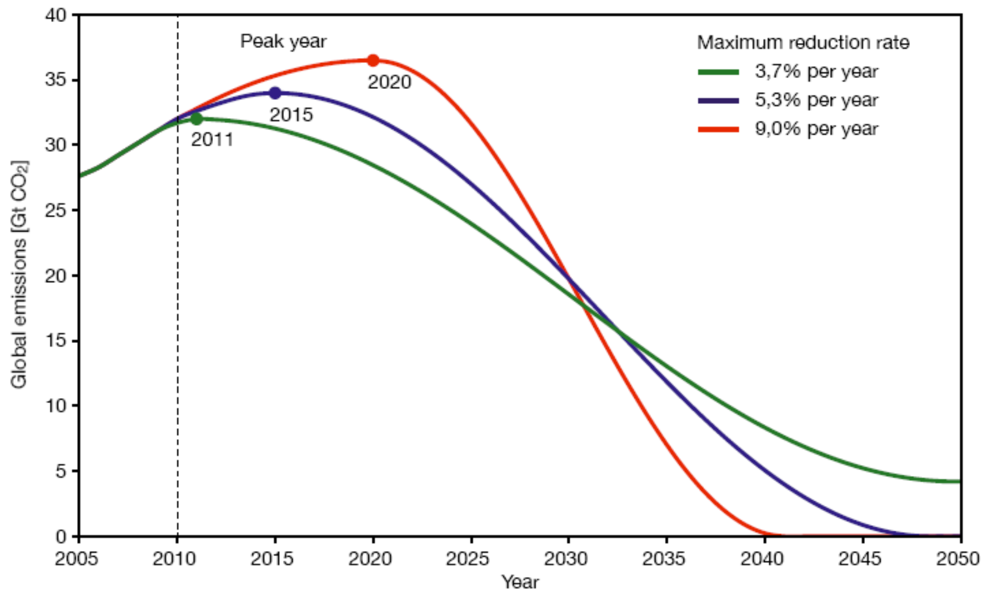
A study by Meinshausen and others came to a similar conclusion, illustrating in a dramatic way the cost of delaying the peaking year—see Figure 3.[44] Some of the steeper paths also require negative emissions from around 2040, which would entail the invention and deployment of large-scale programs to extract carbon from the atmosphere. (The study left out the need for continued unavoidable emissions associated with food production and therefore shows the task to be a little easier than in the analysis by Anderson and Bows).

It is clear that limiting warming to 2ºC is beyond us; the question now is whether we can limit warming to 4ºC. The conclusion that, even if we act promptly and resolutely, the world is on a path to reach 650 ppm and associated warming of 4°C is almost too frightening to accept. Yet that is the reluctant conclusion of the world's leading climate scientists. Even with the most optimistic set of assumptions—the ending of deforestation, a halving of emissions associated with food production, global emissions peaking in 2020 and then falling by 3 per cent a year for a few decades—we have no chance of preventing emissions rising well above a number of critical tipping points that will spark uncontrollable climate change.

---

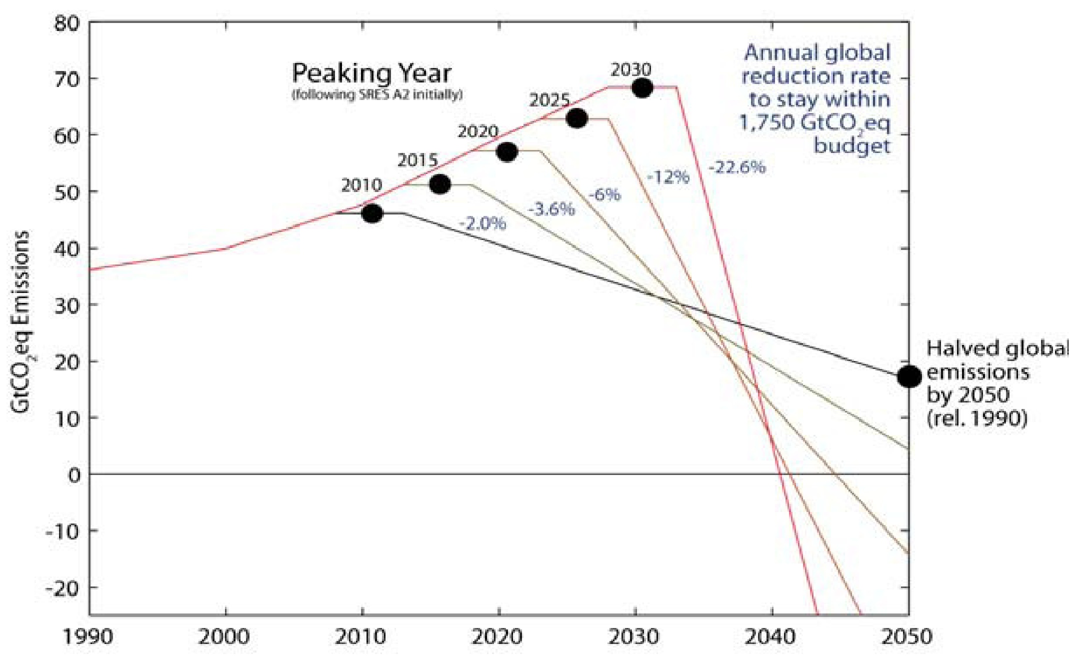
[42] WGBU, *Solving the Climate Dilemma*
[43] In a lecture to the 'Four Degrees and Beyond' conference at the University of Oxford, 28 September 2009.
[44] Malte Meinshausen et al. 'Greenhouse-gas emission targets for limiting global warming to 2°C', *Nature*, Vol 458, 30 April 2009, doi:10.1038/nature08017

Figure 2 Pathways of global emissions 2010-2050 to limit emissions to 750 Gt, giving a 67% chance of limiting warming to 2ºC



Source: WGBU (2009)

Figure 3 Peaking year and emissions reduction rates to stay within a budget aimed at limiting warming to 2ºC



Source: Meinshausen et al. (2009)

The Earth seems to be locked on a path leading to a very different climate, a new and much less stable era lasting many centuries before natural processes eventually establish some sort of equilibrium. Whether human beings will still be a force on the planet, or even survive, is a moot point.

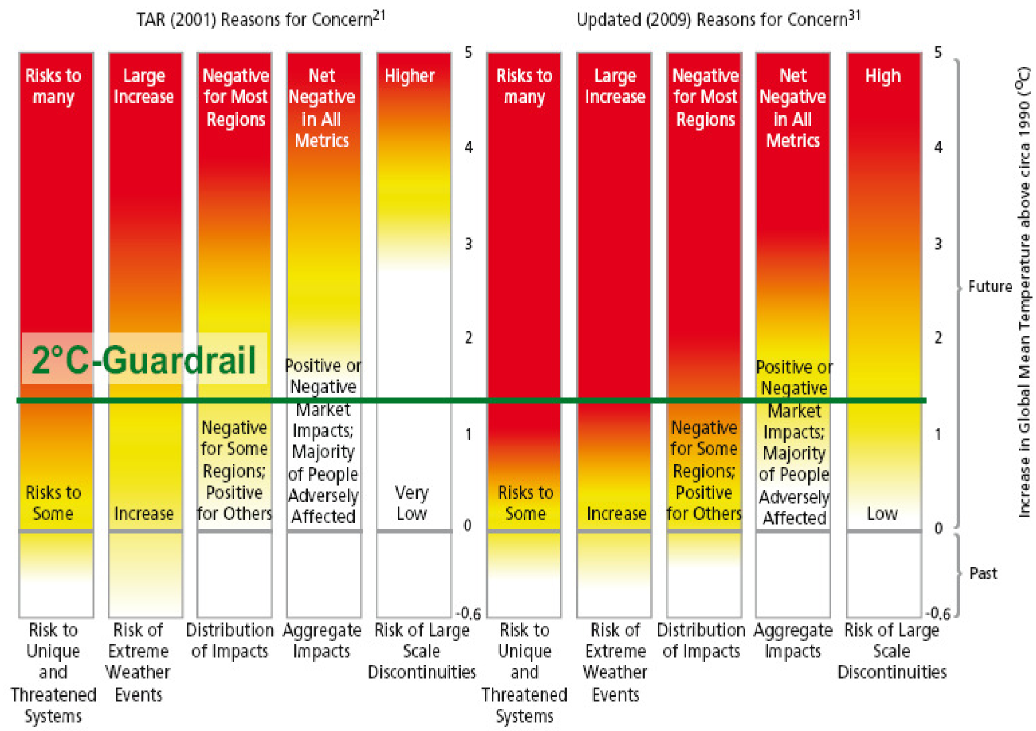
These conclusions are alarming, to say the least, but they are not alarmist. Rather than choosing or interpreting numbers to make the situation appear worse than it could be, following Kevin Anderson and Alice Bows I have chosen numbers that err on the conservative side, i.e., numbers that reflect a more buoyant assessment of the possibilities. A more neutral assessment of how the global community is likely to respond would give an even bleaker assessment. For example, the analysis excludes non-CO_2 emissions from aviation and shipping. It also excludes the effect of aerosols, the tiny particles that mask some of the warming otherwise built in to the system. The clean-up of urban air pollution in China and India—through laws requiring use of cleaner fuels, fitting catalytic converters to vehicles and mandating scrubbers on power plants—would bring on the warming more quickly, perhaps as early as 2060. And, while the analysis incorporates conventional carbon-climate feedback effects—the weakening capacity of land and ocean sinks to soak up carbon—it does not account for the possibility of others such as the ice-albedo effects from Arctic warming that may hasten the approach of a 650 ppm world and take us well beyond it.

Some implications

What does it all mean? I don't plan to dwell on the likely impacts of a four-degree world, except to refer to the famous "burning embers" diagram. Figure 4 shows the most recent assessment of the risks of various impacts, with redder areas indicating higher risks.[45] Until recently we thought we were reasonably comfortably located in the lower left corner, i.e. that 2°C was an achievable aim and the impacts of 2°C warming were worrying but manageable. With a better understanding of the higher risks of even 2°C of warming, and the realisation that 2°C is unattainable and we will be lucky not to reach 4°C, we suddenly find ourselves in the top right hand quarter of the diagram.

[45] Katherine Richardson et al., *Synthesis Report*, from the Climate Change: Global Risks, Challenges & Decisions conference, University of Copenhagen, Copenhagen, 2009, Figure 8

Figure 4 The "burning embers" diagram showing updated assessments of risks of impacts associated with varying degrees of warming



Source: Richardson et al. (2009)

These facts must cause us to rethink entirely how the future will play out because the presence of feedback effects and tipping points calls into question some of the most fundamental assumptions of climate change negotiations. The belief that we can stabilise the climate at a specified concentration of greenhouse gases in the atmosphere, with an associated increase in average global temperature, rests on assumptions that are not well founded in the science. The problem is that global warming is likely to trigger its own 'natural' sources of new emissions and interfere with the Earth's capacity to remove carbon from the atmosphere.

The Earth's climate is not like a machine whose temperature can be regulated by turning some policy knobs; it is a highly complex system with its own regulatory mechanisms. Some of the relationships among variables are non-linear, so that a slight increase in warming can cause a large shift in other aspects of the climate.

Paleoclimatologists have known this for a long time, but it is only in the last few years that the idea has been linked explicitly to today's global warming.[46] If we look at a chart showing the climate history of the Earth stretching back over many millenniums we do not see smooth transitions from ice ages to 'interglacial' or warm periods (such as the one we are now in). The transitions are sometimes dramatic, with sharp changes in the world's climate occurring over mere decades, probably due to amplifying feedback effects. So climate states can end abruptly once certain thresholds are crossed, setting off accelerated warming that is stopped only when a natural limit is reached, such as the disappearance of ice from Earth.[47]

After their 2008 review of the dangers of climate tipping points, a group of leading climate scientists wrote: 'Society may be lulled into a false sense of security by smooth projections of global change.'[48] The extent to which policy makers and their advisers have been lulled into a false sense of security is apparent from the sudden emergence of 'overshooting' strategies, now adopted explicitly or implicitly by almost every government in the world, including Britain's and Australia's. Overshooting was the strategy recommended in both the Stern Review and the Garnaut Report. Nicholas Stern wrote that aiming for stabilisation at 450 ppm 'would require immediate, substantial and rapid cuts in emissions that are likely to be extremely costly'.[49] Instead, the world should aim to stabilise at a politically achievable 550 ppm, a target also taken up by Ross Garnaut in his 2008 report. It is the path adopted by the Obama Administration too.

Faith in our ability to overshoot then return to a safer climate simply fails to understand the science—whatever we do we will be stuck with the results for a very long time. If carbon dioxide concentrations reach 550 ppm, after which emissions fell

---

[46] I am grateful to Andrew Glikson and Graeme Pearman for discussions on these themes.

[47] Other factors driving abrupt climate changes include vulcanism, asteroid and comet impacts, methane releases from sediments and the effects of radiation from supernovae. G. Keller, 'Impacts, Volcanism and Mass Extinction: Random coincidence or cause and effect?', *Australian Journal of Earth Sciences*, vol. 52, issues 4 & 5, pp. 725-757, 2005; Andrew Glikson, 'Asteroid/comet impact clusters, flood basalts and mass extinctions: Significance of isotopic age overlaps', *Earth and Planetary Science Letters*, vol. 236, pp. 933-37, 2005; David Archer, *The Long Thaw*, Princeton University Press, Princeton, 2009; Steffensen et al. 'High-Resolution Greenland Ice Core Data Show Abrupt Climate Change Happens in Few Years'; Hansen et al., 'Target Atmospheric CO_2: Where Should Humanity Aim?'

[48] Lenton et al., 'Tipping elements in the Earth's climate system', p. 1792

[49] Stern, *The Economics of Climate Change*, p. 194

to zero, the global temperature would continue to rise for at least another century.[50] Moreover, once we reach 550 ppm a number of tipping points will have been crossed (see Figure 1) and all the efforts humans then make to cut their greenhouse gas emissions may be overwhelmed by 'natural' sources of greenhouse gases. In that case, rather than *stabilising* at 550 ppm, 550 will be just a level we pass through one year on a trajectory to who knows where—1000 ppm perhaps.

The new understanding of the climate system and the likely influence of tipping points induced by human intervention also forces us to reconsider one of the other foundations of international negotiations and national climate strategies, the belief in our ability to adapt. Underlying the discussion of adaptation is an unspoken belief that, because global warming will change things slowly, predictably and manageably, we (in rich countries) will be able to adapt in a way that broadly preserves our way of life. Wealthy countries can easily afford to build flood defences to shield roads and shopping centres from storm surges, and we can 'climate-proof' homes against the effects of frequent heat waves.

Yet if our belief in our ability to stabilise the Earth's climate is misconceived then so is belief in our ability to adapt easily to climate change. If instead of a smooth transition to a new, albeit less pleasant, climate, warming sets off a runaway process, adaptation will be a never-ending labour. If warming rises above 3 or 4 degrees the chances of severe and abrupt change become high. A harsh and prolonged drought can wipe out an entire region's food production. Fertile plains can turn to dust bowls. A week of temperatures above 40°C can kill tens of thousands of people.

Of course, for people in poor countries adaptation means something entirely different. The effects of warming will be more cruel and their ability to adapt is much more limited.

In sum, the most important assumptions on which international negotiations and national policies are founded—that we can stabilise the climate at some level, that overshooting and returning to a lower target is feasible, and that we can accommodate

---

[50] J. A. Lowe, C. Huntingford, S. C. B. Raper, C. D. Jones, S. K. Liddicoat and L. K. Gohar, 'How difficult is it to recover from dangerous levels of global warming?', *Environmental Research Letters*, vol. 4, 2009. In the simulation where emissions are set to zero in 2050 as concentrations reach 550 ppm CO_2, the temperature rises by an additional 0.2°C through to 2150.

2 or more degrees of warming by adapting to it—have no foundation in the way the Earth's climate system actually behaves. When one understands these facts, the state of political debate around the world takes on an air of unreality. Rich country policies—including cutting emissions by a few per cent and outsourcing most of the cuts to developing countries; waiting for carbon capture and storage technology to save the coal industry and continuing to pollute at high levels until that happens; planning the construction of new coal-fired power plants; and even, in Australia, entertaining the idea of exporting brown coal—are so at odds with the scale and urgency of the emission cuts demanded by the science as to be almost laughable. They reflect a child-like belief that climate change can be averted by ignoring the truth and hoping for the best, a form of wishful thinking whose costs will prove incalculable.

We moderns have become accustomed to the idea that we can modify our environment to suit our needs, and have acted accordingly for some three hundred years. We are now discovering that our intoxicating belief that we can conquer all has come up against a greater force, the Earth itself. We are discovering that humans cannot regulate the climate; the climate regulates us. The prospect of runaway climate change challenges our technological hubris and our Enlightenment faith in reason. The Earth may soon demonstrate that, ultimately, it cannot be tamed and that the human urge to master nature has only roused a slumbering beast.