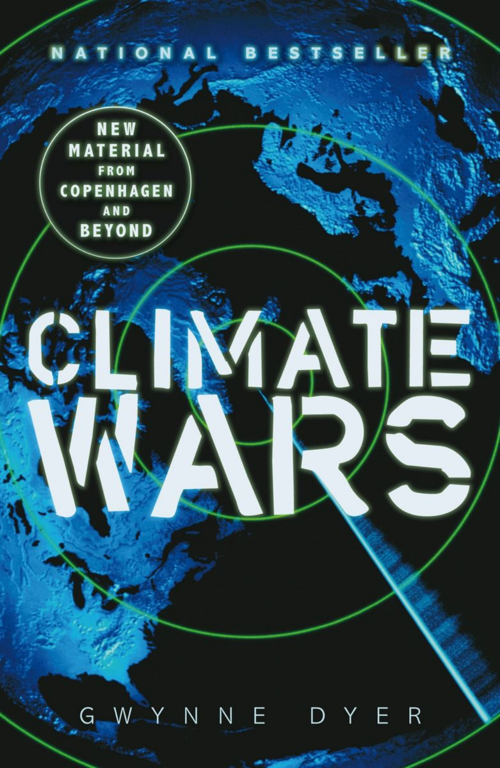
NATIONAL BESTSELLER
NEW MATERIAL FROM COPENHAGEN AND BEYOND
CLIMATE WARS
GWYNNE DYER

Contents

Introduction

> Recent scientific evidence has . . . given us a picture of the physical impacts on our world that we can expect as our climate changes. And those impacts go far beyond the environmental. Their consequences reach to the very heart of the security agenda.
>
> —Margaret Beckett,
> former British foreign secretary

THIS BOOK IS AN ATTEMPT, peering through a glass darkly, to understand the politics and the strategies of the potentially apocalyptic crisis that looks set to occupy most of the twenty-first century. There are now many books available that deal with the science of climate change and some that suggest possible approaches to getting the problem under control, but there are few that venture very far into the grim detail of how real countries experiencing very different and, in some cases, overwhelming pressures as global warming proceeds, are likely to respond to the changes. Yet we all know that it's mostly politics, national and international, that will decide the outcomes.

Two things in particular persuaded me that it was time to write this book. One was the realization that the first and most important impact of climate change on human civilization will be an acute and permanent crisis of food supply. Eating regularly is a non-negotiable activity, and countries that cannot feed their people are unlikely to be "reasonable" about it. Not all of them will be in what we used to call the "Third World"—the developing countries of Asia, Africa and Latin America.

The other thing that finally got the donkey's attention was a dawning awareness that, in a number of the great powers, climate change scenarios are already playing a large and increasing role in the military planning process. Rationally, you would expect this to be the case, because each country pays its professional military establishment to identify and counter "threats" to its security, but the implications of their scenarios are still alarming. There is a probability of wars, including even nuclear wars, if temperatures rise two to three degrees Celsius. Once that happens, all hope of international cooperation to curb emissions and stop the warming goes out the window.

As this is a book about the political and strategic consequences of climate change, for the basic science and some of the commoner physical global-warming scenarios I have depended mainly on published secondary sources, such as the 2007 *Intergovernmental Panel on Climate Change Fourth Assessment Report* and the 2006 *Stern Review on the Economics of Climate Change*, supplemented and updated with interviews where necessary. Indeed, in some ways the interviews are the real foundation of the book: trekking around a dozen countries talking to the scientists, soldiers, bureaucrats and politicians who are immersed in these issues on a daily basis has been an enlightening experience, and one that did much to restore my trust in the rationality of human beings. All indented quotations in the text are taken verbatim from my interviews with the speakers unless some other source is given.

I have not bothered to revisit the arguments that once had to be made to persuade people that human civilization is having a serious effect on the climate. There must remain some infinitesimal possibility that the sceptics are right and everybody else is wrong, but the evidence for global warming caused by human activities is so strong that urgent action is required. The potential cost of doing too little, too late is vastly greater than the cost that might be incurred by doing more to fight global warming than turns out, at some later date, to have been strictly necessary.

The scenarios that precede each chapter are not intended to be predictions, but only examples of the kinds of political crisis that could be caused by climate change. Neither are they components in some larger vision of how the future will unfold; each stands alone, and it is of no importance if one should contradict another. When I quote experts from interviews or other sources in these scenarios, it is solely to illustrate that some assumption I am making is regarded as plausible by the experts, and does not imply that the person quoted agrees with or has even seen the scenario in question. The dates I have assigned to the various scenarios are particularly arbitrary, and could easily be pushed down several decades if global warming proceeds more slowly than the latest evidence seems to suggest. All that said, I have tried to make the scenarios as credible as possible, drawing on a lifetime of analyzing how the world works as an international-affairs journalist. Sometimes I even got it right.

And here, right up front, are four conclusions that I have reached after a year of trailing around the world of climate change—four important things that I did not fully understand when I started this trip. First, this thing is coming at us a whole lot faster than the publicly acknowledged wisdom has it. When you talk to the people at the sharp end of the climate business, scientists and policy-makers alike, there is an air of suppressed panic in many of the conversations. We are not going to get through this without taking a lot of casualties, if we get through it at all.

Second, all the stuff about changing the light-bulbs and driving less, although it is useful for raising consciousness and gives people some sense of control over their fate, is practically irrelevant to the outcome of this crisis. We have to decarbonize our economies wholesale, and if we haven't reached zero greenhouse gas emissions globally by 2050—and, preferably, 80 percent cuts by 2030—then the second half of this century will not be a time you would choose to live in. If we have done it right, on the other hand, then the fuel that runs our cars and planes, like the power that lights our homes and drives our industries, will not produce carbon dioxide or other greenhouse gases. Use as much as you want, or can afford.

Third, it is unrealistic to believe that we are really going to make those deadlines. Maybe if we had got serious about climate change fifteen years ago, or even ten, we might have had a chance, but it's too late now. Global greenhouse-gas emissions were rising at about 1 percent a year when the original climate change treaty was signed in 1992; now they are growing at 3 percent a year, and most of Asia, home to half of the human race, is rapidly moving into industrialized consumer societies. To keep the global average temperature low enough to avoid hitting some really ugly feedbacks, we need greenhouse-gas emissions to be falling by 4 percent *now*, and you just can't turn the supertanker around that fast. So we are going to need geo-engineering solutions as stopgaps to hold the temperature down while we work at getting our emissions down, and we should be urgently examining our options in this area now. There is a very broad consensus that we should not even discuss geo-engineering techniques because of the "moral hazard" they represent—because we might choose geo-engineering methods *instead of* emissions reductions—but we get only one shot at solving this problem, and we will probably fail without geo-engineering.

And fourth, for every degree that the average global temperature rises, so do the mass movements of population, the number of failed and failing states, and very probably the internal and international wars. Which, if they become big and frequent enough, will sabotage the global cooperation that is the only way to stop the temperature from continuing to climb.

I should mention, finally, that I am known in some circles for having worried aloud at some length about the threat of nuclear war during the bad old days of the Cold War. (So much so that one well-known environmentalist, whom I have known for half my life, accused me of "hopping aboard" the issue of climate change when I asked him for an interview, as if I hadn't paid for the tickets to ride his train.) But the threat of nuclear war and nuclear winter that hung over the late twentieth century, the danger of runaway climate change that besets us now, and the unknown but predictably terrifying crises that will imperil our children and our grandchildren even if we stop global warming, are all facets of the same basic truth: as a species, we have achieved critical mass.

There are now so many of us and we consume so much that it would take about 30 percent more planet than we actually have to support us sustainably. If all the rest of the world's people attained a "Western" standard of living, we would need three to four planets. This particular crisis about the climate is soluble, mainly by moving on from the technologies of the Industrial Revolution to ones that are less crude and less damaging environmentally, but our powers have grown so great that in a larger sense the crisis is now permanent, although its specific character will change from time to time. We may not even have the luxury of having to confront only one apocalyptic crisis at a time (although that would be nice). For example, by the 2020s, we may be plunged into a struggle over the proper role of artificial intelligence that is just as important to the future of the human race as getting our impact on the climate under control. And out beyond the "known unknowns," as former U.S. secretary of defense Don Rumsfeld put it, lie the "unknown unknowns."

As the petty officer who dominated my life during navy basic training used to say: "If you can't take a joke, you shouldn't have joined."

SCENARIO ONE:
THE YEAR 2045

Average global temperature: 2.8 degrees Celsius higher than 1990.

Global population: 5.8 billion.

Since the final collapse of the European Union in 2036, under the stress of mass migration from the southern to the northern members, the reconfigured Northern Union (France, Benelux, Germany, Scandinavia, Poland and the old Habsburg domains) has succeeded in closing its borders to any further refugees from the famine-stricken Mediterranean countries. Italy, south of Rome, has been largely overrun by refugees from even harder-hit North African countries and is no longer part of an organized state, but Spain, Padania (northern Italy) and Turkey have all acquired nuclear weapons and are seeking (with little success) to enforce food sharing on the better-fed countries of northern Europe. Britain, which has managed to make itself just about self-sufficient in food by dint of a great national effort, has withdrawn from the continent and shelters behind its enhanced nuclear deterrent.

Russia, the greatest beneficiary of climate change in terms of food production, is the undisputed great power of Asia. However, the reunification of China after the chaos of the 2020s and 2030s poses a renewed threat to its Siberian borders, for even the much reduced Chinese population of eight hundred million is unable to feed itself from the country's increasingly arid farmland, which was devastated by the decline of rainfall over the north Chinese plain and the collapse of the major river systems. Southern India is re-emerging as a major regional power, but what used to be northern India, Pakistan and Bangladesh remain swept by famine and anarchy, due to the collapse of the flow in the glacier-fed Indus, Ganges and Brahmaputra rivers and the increasingly frequent failure of the monsoon. Japan, like Britain, has withdrawn from its continent and is an island of relative prosperity bristling with nuclear weapons.

The population of the Islamic Republic of Arabia, which had risen to forty million, fell by half in five years after the exhaustion of the giant Ghawar oil field in 2020, and has since halved again due to the exorbitant price of what little food remains available for import from any source. Uganda's population, 5 million at independence in 1962, reached 110 million in 2030 before falling back to 30 million, and the majority of the survivors are severely malnourished. Brazil and Argentina still manage to feed themselves, but Mexico has been expelled from the North American Free Trade Area, leaving the United States and Canada with just enough food and water to maintain at least a shadow of their former lifestyles. The Wall along the U.S.-Mexican border is still holding.

Human greenhouse-gas emissions temporarily peaked in 2032, at 47 percent higher than 1990, due largely to the dwindling oil supply and the Chinese Civil War. However, the release of thousands of megatons of methane and carbon dioxide from the melting permafrost in Arctic Canada, Alaska and Siberia has totally overwhelmed human emissions cuts, and the process has slid beyond human ability to control. The combined total of human and "neo-natural" greenhouse-gas emissions continues to rise rapidly, and the average global temperature at the end of the century is predicted to be eight or nine degrees Celsius higher than 1990.

Prognosis: Awful.

CHAPTER ONE
The Geopolitics of Climate Change

The scenario I've just described is not the sort that the climate modellers produce; they wisely stay well clear of any attempt to describe the political, demographic and strategic impacts of the changes they foresee. My scenario also posits a higher global average temperature for 2045 than the bulk of the models predict, but 2.8 degrees Celsius higher by that date is within the range of possibility, especially if some of the positive feedback mechanisms, such as the partial failure of the oceanic carbon sinks, the melting of the permafrost, and an ice-free Arctic Ocean in the summertime, begin to operate within this period. Unhappily, recent data from the tropical oceans, the permafrost belt and the Arctic Ocean suggest that all these feedbacks may be starting to kick in now, much earlier than expected.

The scenario also assumes that the governments of the planet will not have taken advantage of the twenty-year window of opportunity that we still have to get global emissions of greenhouse gases down by 80 percent. It assumes that mid-century will see the world on the upper path of global heating, with the planet's average temperature already two or three degrees Celsius hotter and heading for eight, nine or ten degrees hotter by century's end. In this world, our worries are not just hotter summers, bigger hurricanes, rising sea levels and polar bears swimming for their lives. We are trying to avoid megadeaths from mass starvation and, quite possibly, from nuclear wars—and the odds aren't good.

This is a world in which food imports are no longer available at any price, as there is a global food shortage. But there are still relative winners and relative losers: the higher-latitude countries—northern Europe, Russia, Canada—are still getting adequate rainfall and are able to feed themselves, while those in the mid-latitudes are in serious trouble. Even the United States has lost a large amount of its crop-growing area as the rain fails to fall over the high plains west of the Mississippi, persistent droughts beset the southeast, and the rivers that provided irrigation water for the Central Valley of California cease to flow in the summertime. Countries of smaller size, like Spain, Italy and Turkey on the northern side of the Mediterranean (not to mention those on the southern side), find that their entire land area is turning into desert and that they can no longer feed their populations. The northeastern monsoon that brought rain to the north Chinese plain has failed, and the rivers that watered southern China have suffered the same fate as those that provided California's water: now they only flow in the wintertime.

This is a world where people are starting to starve, but it is not always the familiar scene of helpless peasant societies facing famine with numb resignation. Some of the victims now are fully developed, technologically competent countries, and their people will not watch their children starve so long as there is any recourse, however illegitimate, that might save them. So the lucky countries in the northern tier that can still feed themselves—but have little or no food to spare—must be able to turn back hordes of hungry refugees, quite probably by force. They must also be able to deal with neighbours who try to extort food by threats—and these desperate neighbours may even have nuclear weapons. Appeals to reason will be pointless, as it is reasonable for nations to do anything they can to avoid mass starvation.

If the climate modellers will not generate this kind of scenario, who will? The military, of course.

The military profession, especially in the long-established great powers, is deeply pessimistic about the likelihood that people and countries will behave well under stress. Professional officers are trained to think in terms of emergent threats, and this is as big a threat as you are going to find. Never mind what the pundits are telling the public about the perils of climate change; what are the military strategists telling their governments? That will tell us a great deal about the probable shape of the future, although it may not tell us anything that we want to hear.

In Britain, climate change has been taken seriously at the official level for a long time, and the British Armed Forces are free to discuss any scenarios they want. The *DCDC Global Strategic Trends Programme 2007–2036*, third edition, 2006, a ninety-one-page document produced by the Development, Concepts and Doctrine Centre within the British Ministry of Defence, is "a source document for the development of UK Defence Policy."

In many ways, it is a remarkably sophisticated document. At one point, for example, it observes that "by the end of the period [2036] it is likely that the majority of the global population will find it difficult to 'turn the outside world off.' ICT [information and communication technology] is likely to be so pervasive that people are permanently connected to a network or two-way data stream with inherent challenges to civil liberties; being disconnected could be considered suspicious." But on the political and strategic impacts of climate change, it is surprisingly terse. Here is all it has to say on the matter:

> The future effects of climate change will stem from a more unstable process, involving sudden and possibly in some cases catastrophic changes. It is possible that the effects will be felt more rapidly and widely than anticipated, leading, for example, to an unexpected increase in extreme weather events, challenging the individual and collective capacity to respond . . .

> Increasing demand and climate change are likely to place pressure on the supply of key staples, for example, a drastic depletion of fish stocks or a significantly reduced capacity to grow rice in SE Asia or wheat on the US plains. A succession of poor harvests may cause a major price spike, resulting in significant economic and political turbulence, as well as humanitarian crises of significant proportions and frequency . . .
>
> Water stress will increase, with the risk that disputes over water will contribute significantly to tensions in already volatile regions, possibly triggering military action and population movements . . . Areas most at risk are in North Africa, the Middle East and Central Asia, including China whose growing problems of water scarcity and contamination may lead it to attempt to re-route the waters of rivers flowing into neighbouring India, such as the Brahmaputra . . .
>
> A combination of resource pressure, climate change and the pursuit of economic advantage may stimulate rapid large-scale shifts in population. In particular, sub-Saharan populations will be drawn towards the Mediterranean, Europe and the Middle East, while in Southern Asia coastal inundation, environmental pressure on land and acute economic competition will affect large populations in Bangladesh and on the East coast of India. Similar effects may be felt in the major East Asian archipelagos, while low-lying islands may become uninhabitable.

There now, that wasn't so bad, was it? A shortage of fish here, a major price spike in food there, a little border war between China and India over re-routing the rivers, and a few tens of millions of climate refugees heading north out of sub-Saharan Africa and Bangladesh. If that's the sum of the damage climate change that will bring in the next thirty years, we can live with that.

Unfortunately, that isn't the end of it. This exercise in future-gazing only takes us out to 2036, not to 2045. Far more importantly, it is dated December 2006, which means that the climate forecasts it is using come from the Intergovernmental Panel on Climate Change's 2001 report, not its 2007 report. Essentially, the data it is using are on average close to ten years old. That makes a big difference, because the data and the forecasts have been getting steadily worse. The next iteration of the DCDC report will at least refer to the 2007 IPCC report (although that is already seriously out of date, too), and is likely to feature much darker scenarios on the climate-change front.

So, if the British Armed Forces aren't producing up-to-date scenarios about the political and strategic impacts of climate change, who is? The American military? But here we have the problem that the U.S. government, from the inauguration of President George W. Bush in January 2001 until sometime in late 2006, was in complete denial about climate change. In subsequent months the phrase "climate change" was finally heard to pass the president's lips unaccompanied by disparaging remarks several times, so, in late March 2007, the U.S. Army War College sponsored a two-day conference on "The National Security Implications of Climate Change," at which civilian strategists and active duty and retired officers explored a wide range of climate-related security issues. It seems clear that the military had been chafing at the bit for some time previously, however, since the following month saw the publication of a study that had been in the works for at least two years. At the time when it was commissioned, no bureaucratic warrior experienced in Washington's ways would have risked putting his or her name on a study of the geopolitics of climate change, so the Pentagon farmed the job out to the CNA Corporation.

> I have long been interested in and concerned about how environment affects security, and I spent eight years at the Department of Defense with that portfolio,

> environmental security. I was approached by a group of foundations several years ago and asked specifically if I would examine the national security implications of climate change, and for that purpose I assembled the Military Advisory Board of retired three- and four-star generals to assist us in that effort.
>
> In our report, we were looking primarily over the next thirty to forty years. There are certainly disruptive events that could potentially occur earlier. An extreme weather event, or multiple extreme weather events, could occur at any time. But the more significant implications probably occur over the next several decades, and then of course far into the future. Unless we begin to reduce greenhouse-gas emissions and change the way we use energy, we really have some frightening futures.
>
> —Sherri Goodman, general counsel, CNA Corporation

The CNA Corporation is actually the old Center for Naval Analyses, descended from the group of scientists who brought the fledgling methodology of "operational research" to bear on the problem of anti-submarine warfare during the Second World War, and subsequently on other problems of naval strategy and tactics as well. It is now described as "a federally funded research and development center serving the Department of the Navy and other defense agencies." It produced its report, *National Security and Climate Change*, in April 2007.

The exercise involved choosing eleven recently retired three- and four-star generals and admirals from all four services, exposing them to the views of a large number of people working on climate change or related fields, and then writing a study on which the retired military men were asked to comment and elaborate. It created quite a stir when it was published, precisely because it effectively circumvented the Bush ban on treating climate change as a real and serious phenomenon.

> You already have great tension over water [in the Middle East]. These are cultures often built around a single source of water. So any stresses on the rivers and aquifers can be a source of conflict. If you consider land loss, the Nile Delta region is the most fertile ground in Egypt. Any losses there [from a storm surge] could cause a real problem, again because the region is so fragile . . .
>
> We will pay for this one way or another. We will pay to reduce greenhouse-gas emissions today, and we'll have to take an economic hit of some kind. Or we will pay the price later in military terms. And that will involve human lives. There will be a human toll. There is no way out of this that does not have real costs attached to it.
>
> —General Anthony C. "Tony" Zinni, USMC (Ret.),
> former commander in chief, U.S. Central Command,
> *National Security and Climate Change*, April 2007

The *National Security and Climate Change* study is sixty-two pages long and very well sourced, but it doesn't really offer scenarios. It covers all the bad things that may happen if global warming progresses past a certain point, region by region, but it doesn't even specify what that point is. Indeed, it resembles a more concise version of all the books that have been published by various luminaries over the past couple of years rehearsing all the undesirable things that will happen to us if we don't pull our socks up and deal with global warming: a dab of science, a shopping list of small and large disasters in no particular order (not even in a likely time sequence), and a good deal of exhortation to take this seriously.

The real point of the exercise was probably to persuade a largely military audience of the importance of climate change by having the retired generals and admirals give it their imprimatur. A panel of experts wrote the actual report, but the senior officers were each given an entire page to express their views on the contents and the topic—and it is their testimony that is the heart of the matter. They are intelligent men of considerable experience, so they offer coherent and convincing testimony. But they are clearly selling something.

> People are saying they want to be convinced, perfectly. They want to know the climate science projections with 100 percent certainty. Well, we know a great deal, and even with that, there is still uncertainty. But the trend line is very clear. We never have 100 percent certainty. We never have it. If you wait till you have 100 percent certainty, something bad is going to happen on the battlefield. That's something we know. You have to act with incomplete information. You have to act based on the trend line . . .
>
> The situation, for much of the Cold War, was stable. And the challenge was to keep it stable, to stop the catastrophic event from happening. We spent billions on that strategy. Climate change is exactly the opposite. We have a catastrophic event that appears to be inevitable. And the challenge is to stabilize things—to stabilize carbon in the atmosphere. Back then, the challenge was to stop a particular action. Now, the challenge is to inspire a particular action. We have to act if we're to avoid the worst effects.
>
> —General Gordon R. Sullivan, USA (Ret.),
> former chief of staff, U.S. Army,
> *National Security and Climate Change*, April 2007

What they are selling is a mission. The next mission of the U.S. Armed Forces is going to be the long struggle to maintain stability as climate change continually undermines it. The "war on terror" has more or less had its day, and besides, climate change is a real, full-spectrum challenge that may require everything from special forces to aircraft carriers. So it's time to jolt the rank and file of the officer corps out of their complacency, re-orient them towards the new threat, and get them moving.

Does this sound cynical? I don't really mean it to. The professional military exist because the civilian societies that pay for them believe they are necessary, and in a world of complexity and chance, where universal love has not yet been established as a governing principle, there are occasions when they are needed. It is their job to identify and define threats to the well-being of the society that employs them, and it is only as a by-product of that process that these threats also provide further justifications for the existence of the armies and navies. It took them a while, given the roadblock of the Bush administration, but they are definitely there now.

> Michael Klare: Not just the U.S. military but also the intelligence community . . . view climate change as a major factor in what the world will look like (in the future) and the consequences for national security, and they are deeply concerned about this.
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> GD: What do you think made them shift?
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> Michael Klare: Like everybody else, I think it's a change in consciousness. That's a combination of zeitgeist and the work of Albert Gore and the IPCC—everybody's consciousness has been changed by all of that. Number two, the scientific evidence has become overwhelming in the past couple of years, so they've been affected by that just like everybody else.
>
> GD: Is there also an element of opportunism here? The military always need threats in order to justify their budget. Is this a new one?
>
> Michael Klare: I would say that it's as much fatigue with their current mission as opportunism. Their current mission is Iraq and Afghanistan, and I know that the professional military is completely sickened and fatigued and exhausted with that mission, and I think that it must

> be somewhat refreshing for them to talk about something that bears no taint whatsoever of the Bush administration, the Global War on Terror, Iraq, Afghanistan and so on.
>
> —Michael Klare, defense correspondent for *The Nation*

Whatever their motives, the American military and intelligence communities are now fully committed to playing a leading role in the struggle to contain the negative effects of climate change. Indeed, there is some grumbling in Washington that they are out to "militarize" climate change. This new commitment has led to the production, both inside and outside the Pentagon, of serious studies of what the future will look like politically and strategically as global warming progresses, and what the role of the military will be in that world. The most readily available of these studies is *The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change*, co-published by the Center for Strategic and International Studies (CSIS) and the Center for a New American Security (CNAS) in November 2007. (As soon as it was completed, the team who wrote it was asked to brief the National Intelligence Council.)

While CSIS is a long-established Washington think tank with a broad range of interests, the Center for a New American Security is a recent spinoff that focuses more directly on climate change. Both institutions, however, are supervised by people who have been at the heart of American debates on strategic policy for decades. The board of trustees of CSIS includes former U.S. deputy secretary of state Richard Armitage, former secretary of defense Harold Brown, former national security adviser Zbigniew Brzezinski, former secretary of defense William S. Cohen, former secretary of state Henry Kissinger, former assistant secretary of state Joseph Nye, former secretary of defense James Schlesinger, former national security adviser General Brent Scowcroft, USAF (Ret.), and a who's who of corporate CEOs. The board of directors of the CNAS includes former secretary of defense William Perry, former secretary of state Madeleine Albright, former secretary of the navy Richard Danzig, former undersecretary of defense William Lynn, and General Greg Newbold, USMC (Ret.), former director of operations at the Joint Chiefs of Staff. It may also be relevant that the CNAS board of directors and the lead authors for *The Age of Consequences* include a significant number of former senior security officials in the Clinton administrations of 1993–2000.

The lead authors of the three scenarios in the study include John Podesta, who served as chief of staff to President Clinton in 1998–2000, Leon Fuerth, national security adviser to Vice President Gore and a member of the Principals' Committee of the National Security Council in 1993–2000, and R. James Woolsey, Jr., head of the Central Intelligence Agency 1993–95, who served as a foreign policy adviser to the Republican presidential candidate, Senator John McCain, in 2008.

The political/strategic scenarios elaborated by these authors are based on physical climate change scenarios developed from the data in the IPCC's 2007 report by Jay Gulledge, senior scientist and program manager for science and impacts at the Pew Center on Global Climate Change. The non-alarmist, "expected" scenario for 2040 begins with the A1B emission scenario in the IPCC's 2007 report, a scenario that assumes continued rapid economic growth in the emerging industrial powers like China and India, a mid-range estimate for human population growth, and significant advances in non-fossil-fuel energy technologies and in the efficiency with which fossil fuels are used. Of the six different scenarios that the IPCC considered, A1B is neither the most optimistic nor the most pessimistic, but it does assume a continuing widespread dependence on fossil fuels. Under this scenario, the atmospheric concentration of carbon dioxide will be nearing 700 parts per million by the end of the century, although by 2040 it probably will not have passed 500 parts per million yet. (The pre-industrial concentration of carbon dioxide was 280 parts per million, and we are currently at 390 parts per million.)

Most importantly, this first scenario in *The Age of Consequences* accepts the IPCC's conservative assumptions about the "sensitivity" of the climate to increased levels of carbon dioxide in the atmosphere. It assumes that, by 2040, average global temperature has risen only 1.3 degrees Celsius above the 1990 average that the IPCC uses as a baseline, with a best estimate of 2.8 degrees Celsius above the 1990 figure by century's end. As non-alarmist scenarios go, however, it is already pretty worrisome, even for 2040.

The scenario goes something like this. Since temperatures are usually cooler over the oceans, which cover two-thirds of the Earth's surface, an average global temperature rise of 1.3 degrees Celsius would mean that it is 2 degrees Celsius hotter or more over the land masses, even hotter in the middle of the continents, and much hotter in the high latitudes—up to 4 or 5 degrees Celsius hotter in the high latitudes around the poles. Accelerated melting of glacial ice will raise sea levels worldwide by 0.23 metres by 2040 (with much more to come, of course), and that combined with more violent storm systems will produce storm surges that will inundate some densely populated river deltas, especially in South, Southeast and East Asia. Much land will be lost permanently, and tens of millions of refugees will seek new homes and livelihoods in neighbouring areas that are already fully occupied. Some of those areas will be across international frontiers, and the potential for conflict is very high. India, for example, is already building a 2.5-metre fence along the full length of its 3,000-kilometre border with Bangladesh, one of the countries that is likely to generate very large numbers of refugees as its low-lying coastal areas are lost to the sea.

Similar waves of refugees will be created in other parts of the world by massive droughts that drive farmers off their land, as global warming changes the rainfall patterns and deprives the subtropics and the lower mid-latitudes of much of their rain.

There will be enormous pressures on the southern U.S. borders as Central America and the Caribbean reel under the combined impact of failing crops, more severe hurricanes, and sea-level rises. Europe's southern frontiers will face equal pressures from migrants from Africa—another early victim of failing rainfall—while the Mediterranean parts of the European Union will themselves be suffering from chronic and increasing drought. The southwestern United States will suffer more frequent and longer-lasting droughts that cause problems, not only for agriculture, but for its fast-growing cities, while low-lying coastal areas in the Gulf and mid-Atlantic states will face the risk of multiple Hurricane Katrinas. Some small island nations in the Indian and Pacific Oceans may have to be evacuated and abandoned altogether.

The near absence of tentative words like "would" and "may" in this section of the study is quite striking—but then, as the authors say, "It is not alarmist to say that this scenario is the best we can hope for. It is certainly the least we ought to prepare for." It is a deeply conservative forecast that presumes that no positive feedbacks kick in to accelerate the warming—and the authors find it so implausibly optimistic that they immediately offer an alternative scenario for 2040, which they entitle "Severe Climate Change":

> [This alternative scenario] assumes that the [IPCC 2007 report's] projections of both warming and attendant impacts are systematically biased low. Multiple lines of evidence support this assumption, and it is therefore important to consider from a risk perspective. For instance, the models used to project future warming either omit or do not account for uncertainty in potentially important positive feedbacks that could amplify warming (e.g., release of greenhouse gases from thawing permafrost, reduced ocean and terrestrial CO_2 removal from the atmosphere), and there is some

> evidence that such feedbacks may already be occurring in response to the present warming trend. Hence, climate models may underestimate the degree of warming from a given amount of greenhouse gases emitted to the atmosphere from human activities alone. Additionally, recent observations of climate system responses to warming (e.g., changes in global ice cover, sea level rise, tropical storm activity) suggest that IPCC models underestimate the responsiveness of some aspects of the climate system to a given amount of warming. On these premises, the second scenario assumes that omitted positive feedbacks occur quickly and amplify warming strongly, and that the climate system components respond more strongly to warming than predicted. As a result, impacts accrue at twice the rate projected for emission scenario A1B.

And so, we are plunged into the nightmare world of scenario two, a world only thirty years hence in which the average global surface temperature is 2.6 degrees Celsius above 1990 levels, with higher temperatures over land and much higher temperatures in the high latitudes. Accelerated melting of the Greenland and West Antarctic Ice Sheets has already raised sea levels worldwide by half a metre, and storm surges driven by much more powerful weather systems are already causing crippling inundations in low-lying port cities like New York, Rotterdam, Bombay and Shanghai. London might buy itself fifty or a hundred years by building a second, higher Thames Barrier, but in general the outlook is for successive retreats inland to new, makeshift ports that will eventually be inundated in their turn as the sea level continues to rise. This continuing abandonment of existing assets and reinvestment in new, temporary port facilities will impose heavy burdens even on once-rich societies.

Meanwhile, densely populated river deltas, such as those in Bangladesh, Egypt and Vietnam, are already generating huge numbers of refugees as the land is eaten away by successive storm surges. Crop yields are falling steeply in these regions (which provide a disproportionate amount of the world's food). The irreversible destabilization of the ice sheets means that a further sea-level rise of four to six metres is inevitable over the next few centuries, so all the major river deltas are ultimately doomed, and civilization is condemned to centuries of continuous retreat as coastal lands are drowned.

Agriculture has become "essentially non-viable" in the dry subtropics as "irrigation becomes exceptionally difficult because of dwindling water supplies, and soil salination is exacerbated by more rapid evaporation of water from irrigated fields." Desertification is spreading in the lower mid-latitudes. Fisheries are damaged worldwide by coral bleaching, ocean acidification, and the substantial loss of coastal nursery wetlands—but then most major ocean fisheries will probably have collapsed through overfishing well before 2040 anyway, with no help from climate change. The scenario makes no attempt to calculate the global availability of food in 2040, but its many references to refugee flows and regional shortfalls indicate an implicit assumption that there is no longer enough food to go around.

But it is the magnification of these physical effects by likely political and social responses that particularly concerns the author of the "severe" scenario, Leon Fuerth. As he points out in the *Age of Consequences*, "If the environment deteriorates beyond some critical point, natural systems that are adapted to it will break down. This applies also to social organization. Beyond a certain level climate change becomes a profound challenge to the foundations of the global industrial civilization that is the mark of our species."

Region by region, Fuerth assesses the probable impacts. In the United States, agriculture is practically at an end in California's Central Valley due to the failure of the rivers that used to be fed in the summer by the melting snowpack on the Sierra Nevada and Rocky Mountains, and the major cities of the southwest are suffering drastic, permanent water shortages. Rainfall declines steeply over the high plains west of the Mississippi, intensifying reliance on irrigation water pumped up from the giant Ogallala aquifer and speeding its depletion. Coastal populations in the southeastern states who are under constant attack from wild weather events will initially benefit from federal projects to protect them, but the attempts will fail: "The idea of resisting nature by brute engineering will give way to strategic withdrawal, combined with a rear guard action to protect the most valuable of our resources. Optimists might hope for a gradual relocation of investment and settlement from increasingly vulnerable coastal areas. After a certain point, however, sudden depopulation may occur." And under all these stresses, the author suggests, the federal system itself may start to weaken, with Washington offloading the burden of coping with the constant, multiple disasters onto state governments, as its own resources become inadequate for the task.

Meanwhile, the far more severe consequences of climate change in Mexico, Central America and the Caribbean, where drought has become the new normal, puts huge pressure on the U.S. border, where "problems will expand beyond the possibility of control, except by drastic methods and perhaps not even then. Efforts to choke off illegal immigration will have increasingly divisive repercussions on the domestic social and political structure of the United States." (By 2040—although the study does not explicitly mention it—some 20 percent of the U.S. population may be of Hispanic origin.)

Problems with Canada will accumulate, too, over fishing rights on both coasts, over water resources (especially if the U.S. decides to divert water from the Great Lakes, on which two-thirds of Canadians rely, to compensate for the effects of climate change elsewhere), and over navigation and resource rights in the newly ice-free Arctic Ocean. Moreover, the study states that "it cannot be excluded that Canada's tensions with the United States will play into domestic issues affecting the stability of Canada itself: most notably, the Western provinces' new role as oil exporter." (This is presumably a coy reference to separatism in oil-rich Alberta.)

In Latin America generally, the report predicts, severe climate change will be a death blow for democratic governments, and "Chavez-like governments will proliferate." Large regions will become essentially lawless or fall under the control of criminal cartels, and the United States, lacking the means to help local authorities to restore order, "will likely fall back on a combination of policies that add up to quarantine." The study implicitly assumes that the United States has already abandoned its more far-flung strategic commitments by 2040 and withdrawn to Fortress America, but it is a fortress surrounded by hostile neighbours. "The result . . . will be to render the United States profoundly isolated in the Western Hemisphere: blamed as a prime mover of global disaster; hated for measures it takes in self-protection."

Africa is the continent that takes the worst hit from climate change in almost every scenario, and this one is no exception. "The northern tier of African countries (i.e., Morocco, Algeria, Tunisia, Libya) will face collapse as water problems become unmanageable, particularly in combination with continued population growth," writes Fuerth, pointing out that, in Morocco's case, intense drought will destroy not only its irrigation agriculture but also its hydroelectric power generation. The countries of the Maghreb may try to tap into underground aquifers in a "zero-sum struggle for survival," but even the Great Nubian Sandstone Aquifer, currently the object of a US$20-billion Libyan mass irrigation project, would be largely drained in fifty years. Further east, wars between Egypt, Sudan and/or Ethiopia over attempts to divert the waters of the Nile and its tributaries for upstream irrigation projects are a growing possibility by 2040, and the whole Nile Delta is at risk from storm surges.

In sub-Saharan Africa, "hundreds of millions of already vulnerable persons will be exposed to intensified threat of death by disease, malnutrition and strife." The primary cause will be long-term drought, but the weakness of the infrastructure in most African countries will lead to a proliferation of failed states that exacerbates all the problems and generates huge waves of refugees. Many will follow the familiar paths north towards Europe, but there will also be a strong southward flow towards South Africa (which will be facing severe drought problems of its own).

In the Middle East, rapidly growing populations and declining water supplies will intensify existing hostilities everywhere. Attempts at an Israeli-Palestinian peace settlement will be abandoned indefinitely "because of a collective conclusion that the problem of sharing water supplies must be regarded as permanently intractable," and even war between Israel and Jordan over access to water is conceivable. Iraq, Syria and Turkey will become trapped in an "escalating struggle" over Turkey's control of the headwaters of the Tigris and Euphrates rivers. In the Gulf countries there will be a rapid expansion of nuclear power for desalination of sea water, and this will facilitate "the regional proliferation of nuclear weapons as insurance against predation."

All the Asian rivers that rise in the Himalayas and on the Tibetan plateau (Indus, Ganges, Brahmaputra, Salween, Mekong, Yangtze) will initially flood for decades as the glaciers and the snowpack melt, and then shrink drastically, especially in the summer months, once the glaciers and the snowpack are gone. This will lead to food shortages and cross-border disputes over water in the Indian subcontinent, and nuclear-armed India and Pakistan will face the risk of war over the Indus River. (The largest contiguous area of irrigated land on Earth is on the lower reaches of the Indus river system, in Pakistan, but the headwaters of the rivers are in India.) Indian democracy may fail under these stresses.

China's shrinking rivers will affect not only food production across southern China but also the country's ambitious hydroelectric schemes, like the Three Gorges Dam. The weakening of the northeast monsoon will cut grain production on the north Chinese plain, and China's industrialized coastal regions will take a severe battering from rising sea levels and stronger storm systems. The autocratic Chinese regime may seek to fortify its domestic position, rendered shaky by these blows, by directing popular anger outwards, at Taiwan, Japan or even the United States.

Authoritarian regimes are also likely to arise in Europe, especially in Russia, where the regime "will anchor itself ideologically in Russian nationalism, and economically on the basis of a dominant energy position, which it will exploit aggressively." But similar things will be happening politically in Western Europe under the impact of an influx of illegal immigrants from northern Africa and other parts of the continent. It will be an influx "impossible to stop, except by means approximating blockade." Hostility to Muslim communities in particular will increase; efforts to integrate them into the European mainstream will collapse, and "extreme division will become the norm." Economically, the European Union will have its hands full as almost every major port faces inundation and the whole country of the Netherlands has to be rescued from the sea.

Now, there are obvious criticisms that can be levelled at this scenario, and the most prominent ones arise from the American perspective of the author. Borders are not nearly as hard to control as he believes. Even the U.S. border with Mexico could be sealed, at a tiny fraction of the amount spent annually on the war in Iraq, if the United States ever decided that it was willing to forego the constant influx of cheap labour that is facilitated by the current, deliberately porous border controls. The notion that Europe cannot control its sea frontiers with Africa is simply laughable; it is just not yet willing to use physical force to defend them. And Fuerth's exaggerated concern about the reliability of Muslim minorities in Europe, though not without echoes in the debate in Europe itself, is primarily a reflection of post-9/11 American obsessions that do not address contemporary European realities.

Nevertheless, the true insight of Fuerth's analysis lies not in the regional analyses, but in his observation that "massive nonlinear events in the global environment will give rise to massive nonlinear societal events. The specific profile of these events will vary, but very high intensity will be the norm."

> Leon Fuerth: Complexity theory . . . originates in very obscure mathematics that were developed to try to describe extremely unruly physical events, but it has developed a path that runs towards human events as well, and especially towards the interaction of physical and human events, which makes it very interesting for the purposes of dealing with something like climate change.
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> The essential insight in complexity theory would be: Don't think of this as a linear process. Think of it as a process where at any point some small change of inputs could produce a massive, unexpected flip in outputs . . . Expect that any solutions you apply are likely to further disturb the system, leading to an infinite series of surprises. Very different from the kind of approach that is often taken in public policy, which is that you only need to do THIS, and the problem will be solved now and forever . . . Once you realize that, you begin to try to analyze different regions of the world and even different countries from the perspective of how their political systems will change, whether these are domestic or international.
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> GD: What you're saying, essentially, is that we're looking at potential system collapse, politically as well as physically.

> Leon Fuerth: This whole thing is an interaction between human beings as a highly organized industrial civilization, and the world's physics and chemistry and so on, and the consequences of things that we already have done, and set in motion, before we were smart enough to recognize the patterns.
>
> —Leon Fuerth, professor of international affairs, George Washington University, one of the lead authors of *The Age of Consequences*

Among the non-linear political events Fuerth foresees in the event of severe climate change are class warfare "as the wealthiest members of every society pull away from the rest of the population;" an end to globalization and the onset of rapid economic decline owing to the collapse of financial and production systems that depend on integrated worldwide systems; and the collapse of alliance systems and multilateral institutions, including the United Nations. He suggests that massive social upheavals will be accompanied by intense religious and ideological turmoil, in which the principal winners will be authoritarian ideologies and brands of religion that reject scientific rationalism. Even more disturbing (and persuasive) is his observation that "governments with resources will be forced to engage in long, nightmarish episodes of triage: deciding what and who can be salvaged from engulfment by a disordered environment. The choices will need to be made primarily among the poorest, not just abroad but at home. We have already previewed the images, in the course of the organizational and spiritual unravelling that was Hurricane Katrina. At progressively more extreme levels, the decisions will be increasingly harsh: morally agonizing to those who must make and execute them—but in the end, morally deadening."

And so we come to the pandemics facilitated by the collapse of public-health systems in poor countries, the wars (including nuclear wars), and the other second-order consequences of the climate change scenario Fuerth was given. He suggests that we may see abrupt die-offs of the kind that have occurred on a smaller scale among ancient peoples under severe climate stress, and even pre-emptive desertion of urban civilization in some regions. Yet he does not come across as someone who is happy predicting doom; speaking to him, one has the impression that he was surprised, indeed shocked, by where his analysis led him. After all, the average global temperature was only 2.6 degrees Celsius hotter in the scenario Jay Gulledge gave him. (Although that does mean an average of 4 degrees hotter over land, and much more than that in the polar regions.)

In the end, I asked him how credible he thought his "severe" scenario was, compared to the "expected" scenario based on the most recent IPCC report. He replied: "The way more recent information is coming out suggests that the kind of future that's actually already loaded into the environment is better described by the kind of scenario that they gave me to work on—the 'severe' thirty years [scenario]—in which case the question is: what are we going to do to mitigate this so that we don't hand on to our [descendants] the severe one-hundred-year scenario, and what are we going to do to try to adapt to the consequences that may already be loaded into the system?"

In later chapters, I will deal with recent evidence that confirms Fuerth's sense that the severe thirty-year scenario is more credible. I'll also discuss what might be done by way of mitigation. But we should address the third one-hundred-year scenario now: "Catastrophic Climate Change." Written by former CIA head James Woolsey, this scenario assumes an average global temperature 5.6 degrees Celsius hotter than now and a sea level two metres higher (with much more to come). It contains all manner of blood-curdling predictions, such as a Sino-Russian nuclear war in which China's desperate need to resettle tens or hundreds of millions of people driven from its flooded coastlines leads it to try to seize a Siberia made more agriculturally productive by the warming. But it is not as convincing a scenario as its predecessors, mainly because early twenty-first-century American obsessions about Muslims in general and terrorists in particular are transposed almost intact into this scenario that is allegedly about the early twenty-second century. A different kind of scenario for severe climate change is called for at this distance from the present, and a persuasive (though appalling) one is provided by the man who can fairly claim to have been the founder of what we now call "Earth System Science," the British geophysicist James Lovelock.

In Lovelock's second-last book, *The Revenge of Gaia*, published in 2006, he observes that the concentration of carbon dioxide in the atmosphere fell to 180 parts per million in the depths of the last ice age, and rose to 280 parts per million after it ended. The further rise to the current carbon dioxide level of more than 390 parts per million is largely due to human activities since the beginning of the Industrial Revolution, so we have already made as large a change in the composition of the atmosphere as that which occurred between the last time when glaciers covered much of the Northern Hemisphere and the current warm spell.

The change in average global temperature between the depths of the last major glaciation and the long interglacial we now inhabit was about five degrees Celsius, so we may already be committed to an eventual further rise in average global temperature of similar scale. There is no certainty about this, because we do not know to what extent that earlier one-hundred-parts-per-million rise in atmospheric carbon dioxide was supplemented by various feedbacks in order to produce the five-degree-Celsius rise in temperature between the last glacial maximum and now. The extra one hundred parts per million is already in the air (though it has only resulted in a 0.8-degree-Celsius rise in average global temperature so far), so we may already have blown it. But we cannot know that for certain, so it still makes sense to strive to curb our emissions.

However, as Lovelock points out, it is highly unlikely that we will be able to decarbonize the global economy fast enough to avoid a further rise in carbon dioxide concentration to five hundred parts per million or more. This is comparable to the level of carbon dioxide in the atmosphere at the time of the last really hot spell in the Earth's history, at the beginning of the Eocene era, fifty-five million years ago, the so-called Paleocene-Eocene Thermal Maximum (PETM). The world had been warming gradually for some millions of years, and reached a point at which warmer ocean water destabilized the clathrates buried beneath the ocean floor, especially in the North Atlantic. (Clathrates are deposits of methane, continuously produced by bacteria in the deep ocean floor, that are contained in molecular "cages" of frozen water that are stable under the great pressures of those depths. However, the warmer the temperature, the more unstable the cages become and, at a certain point, they are liable to release the methane quite suddenly, resulting in enormous "burps" of methane gas that rise to the sea surface and thence into the atmosphere, where they are a powerful warming agent.)

The PETM episode was caused by the sudden release of between three hundred billion and three trillion tons of fossil carbon, probably mostly in the form of methane gas from the clathrate deposits in the North Atlantic. (Why the North Atlantic? Not clear, although at the time it may have been warmer than other oceans due to some vagary of the currents.) At any rate, the result was that the early Eocene world, which was already somewhat warmer than ours is today, with no ice at either pole, experienced a runaway heating of about six degrees Celsius over a period of only twenty thousand years. Most of the temperature change occurred in two thousand-year bursts at the beginning and end of that period, presumably corresponding to enormous clathrate releases at those times. The remarkable thing, however, is that there was not a mass extinction. There was a significant turnover in the mammal populations, with most of the primitive mammals that had developed since the end of the Cretaceous Period being replaced by the ancestors of modern mammal groups (all of them in small versions adapted to Eocene heat), but there was no actual reduction in the number of species. On the contrary, there was a major diversification of species in the subsequent hot period, when there were both trees and alligators in the polar regions, and the only major loss of species was in the deep ocean regions (again, principally, in the North Atlantic).

The disturbance lasted about two hundred thousand years, during which the lower and middle latitudes of the planet were largely barren of life: deserts predominated on land, and the upper layers of the oceans were effectively semi-deserts too, since the density of marine life plummets once the sea-surface temperature exceeds twenty degrees Celsius. Only in the higher latitudes around the poles were there reasonably temperate conditions in which land and ocean life could thrive—but it did thrive there, as twenty thousand years had given it enough time to migrate and adapt. Human agriculture and fossil fuel burning have already released five hundred billion tons of carbon, which places us within the range estimated for the Eocene event. If that is what we are about to unleash, however, neither we nor the rest of the planet's flora and fauna will have twenty thousand years to adapt: this time things are moving a lot faster, as James Lovelock writes in *The Revenge of Gaia*:

> The Earth has recovered from fevers like this [in the past] . . . but if we continue business as usual, our species may never again enjoy the lush and verdant world we had only a hundred years ago. What is most in danger is civilization; humans are tough enough for breeding pairs to survive, and . . . in spite of the heat there will still be

> places on Earth that are pleasant enough by our standards; the survival of plants and animals through the Eocene confirms it . . . But if these huge changes do occur it seems likely that few of the teeming billions now alive will survive.

So, in Lovelock's hundred-year scenario—or two hundred years, or however long it takes for the full effect of the five-hundred-parts-per-million-plus carbon loading to be fully expressed in terms of higher global temperature—the great bulk of the Earth's land surface turns to desert and scrubland, with only the Arctic basin and Greenland remaining as "the future centres of an appropriately diminished civilization." With luck, a civilization of a few hundred million people might survive in this area, for "the tundra wastelands of Siberia and northern Canada that remain above sea level will be rich with vegetation, and the enlarged Arctic Ocean, filled with algae, may become the fishing grounds of the future." This is such a drastic scenario that I asked almost every climate scientist I interviewed whether it was over the top. Almost all of them took it seriously. In a February 2008 interview, Jay Gulledge:

> It's over the top only in the sense that scientifically we don't actually know what the consequences of our actions are for the Earth system. But everything [Lovelock] says has a functional basis, a theoretical basis. The most disturbing thing about the scenario that he develops is that it's plausible.
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> A lot of people aren't used to thinking in terms of plausibility, and yet they do it any time they buy an insurance policy. One or two percent of people experience a fire at their house in their lifetimes, but all of them who have a mortgage have fire insurance. That's because it's plausible that it could happen, and there's nothing in what Lovelock outlines that's unreasonable . . . The types

of scenarios he draws are often dismissed because they seem so alarmist . . . but even though we don't know what's going to happen, what he says could happen. It's plausible.

CHAPTER TWO
An Inevitable Crisis

> One of the things that struck me on my first day in space is that there is no blue sky. It's something that every human lives with on Earth, but when you're in space, you don't see it. It looks like there's nothing between you and the Earth. And out beyond that, it looks like midnight, with only deep black and stars.
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> But when you look at the Earth's horizon, you see an incredibly beautiful, but very, very thin line. You can see a tiny rainbow of colour. That thin line is our atmosphere. And the real fragility of our atmosphere is that there's so little of it.
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> —Vice Admiral Richard H. Truly, USN (Ret.), former shuttle astronaut and commander of Naval Space Command, *National Security and Climate Change*, April 2007

But the sky looks pretty big from below, and we feel very small beneath it. For this reason, it was very hard for previous generations to imagine that our own actions could affect the climate in any serious way. Even as our numbers and our powers grew, there was little to suggest that our activities were beginning to overwhelm the natural cycles that maintain the stability of the current global climate. Indeed, nobody knew that there had ever been different global climates in the past, some of them much less suitable for human mass civilizations to thrive in, nor did they understand that seemingly minor changes in the composition of the atmosphere could flip the climate from its present state of equilibrium to a quite different state in a relatively short period of time.

So nobody is to blame for the crisis that looms over us. Not my mother, who had five children and contributed to a population explosion that saw the world's population triple from 2.3 billion to 6.7 billion between the end of the Second World War and now. Not William Levitt, who invented the modern suburb in the late 1940s, or Henry Ford, who applied mass-production techniques to the manufacture of automobiles in 1913, or Thomas Newcomen, who devised the first practical steam engine in 1710. And certainly not the first woman who planted seeds with a digging stick ten or twelve thousand years ago and began the agricultural revolution that set us on the path to mass civilization. (In the Neolithic division of labour, women were the gatherers who dealt in plants, while men were the hunters.) None of them could imagine that we might actually change the way the world works to our own disadvantage.

Yet here we are, only six or seven thousand years after our ancestors built the first little cities, and the world is changing before our eyes. Runaway climate change threatens to sweep away our stable, familiar world and replace it with a terrifying chaos of famine, mass migration and war that could cut the human population to a fraction of its present numbers by the end of this century. And with the benefit of hindsight, we can now see that this crisis was inevitable from the moment that some people abandoned the hunting-and-gathering lifestyle and became farmers.

With a regular food supply that could be expanded simply by adding more farmers, the population of the farmers soared: any land that was even marginally suitable for agriculture could support between five and a hundred times as many farmers as hunter-gatherers. And the numbers counted: even though the hunter-gatherers were healthier, had more varied diets, and probably lived more interesting lives, when they came into conflict with the farmers over land, they usually lost. Within perhaps a thousand years, the farmers were a majority of mankind. Now they, and their urban dependants, account for 99.9 percent of the human race, and there are about a thousand times as many of us as there were in the days when everybody was a hunter-gatherer.

The other advantage of being a farmer was that you had a fixed address: you could own more than you could carry. And because the whole approach of farmers is to manipulate the physical environment, not just to cope with what nature provides, technology began to accumulate. Once writing was invented, knowledge started to accumulate at a higher rate, too. It took about ten thousand years, but, by the beginning of the eighteenth century, the combination of scientific knowledge and technological expertise achieved critical mass. If Thomas Newcomen had been struck dead by a meteorite in 1709, somebody else would have invented the steam engine—which unleashed the Industrial Revolution—within the next few decades. Indeed, it would probably have been somebody else in Britain, because that was where the critical mass of technology and scientific perspective came into being at that time.

The same applies to the invention of mass production—not actually by Henry Ford, but it was he who started mass-producing automobiles, which is relevant in the current context. The innovation of far-flung suburbs that made the sprawling metropolises of the present possible could not have come into existence without mass automobile ownership. One thing led to another with something close to inevitability: only the details of who was the actual innovator and when and where it happened were open to chance. So, here we are with about a quarter of the world's 6.7 billion people living in "post-industrial" but still high-consumption societies, and another half of the world's population going through a high-speed recapitulation of both the industrial *and* the consumption revolutions, and, of course, we are in trouble. We have grown very fast, we have appropriated a very large portion of the Earth's resources, and we may end up paying a very high price for it.

Yet nobody is to blame. We didn't realize—couldn't realize, given the state of our knowledge at the time—that our actions might affect the whole biosphere. Only in the past forty years have a few scientists begun to suspect that the climate might be changed by human activities. Only in the past thirty years have some people started to warn that the changes were actually underway, and only in the last twenty years has the science been good enough to pin the changes firmly on human activities. The crisis we face was foreordained from the moment that that first woman planted a seed, but it wasn't obvious to us. So we go into the crisis ill-prepared in both material and psychological terms, and the outcome is uncertain.

> What we're seeing in the climate domain is not just increases in the average surface temperature of the Earth. People really need to understand that the average surface temperature is just an index of the state of the climate. It's sort of like the temperature of your body, and you say "What's a few degrees among friends?," and then you realize that if you have a fever of 40.5 degrees Celsius, even though that's only three and a half degrees above normal, it's potentially fatal. The same thing is true of the world: differences of a few degrees in the average temperature of the world reflect massive changes in the patterns of the climate that are determinative of human well-being. We depend on the climate for the productivity of farms and forests and fisheries, we depend on the climate for the availability of water . . . We are at risk from the climate from heat waves, from floods, from droughts, from wild fires, from sea-level rise. And what we are seeing is all of these things happening faster.

> We are seeing not only a rise in the surface temperature of the planet. We are seeing changes in circulation patterns, changes in storm tracks, increases in flood intensity and frequency, increases in drought intensity and frequency, more and stronger heat waves, more powerful tropical storms—right across the board, everything that is expected to result from global climate change driven by greenhouse gases is not only happening, but it's happening faster than anybody expected.
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> —John Holdren, chief scientific adviser to President Barack Obama

It's the numbers that count, in the end. If there were still only the 250 million human beings who were alive at the time of the Roman empire, we could do almost anything we wanted with impunity: industrialize, eat lots of meat, drive big cars and fly halfway around the planet on holiday. Sooner or later, we would still have to address the issue of our greenhouse-gas emissions, for carbon dioxide stays in the atmosphere for about two hundred years, and even the emissions of a quarter-billion people living that way would eventually accumulate to the point where they had to start moving away from carbon-based fuels for their energy needs. But presuming that our science was good enough by then to figure out what was going on, a mere quarter-billion of us would have plenty of time to make the changes, and run little risk of facing an existential crisis along the way.

The billion people who were alive in 1800, at the very start of the Industrial Revolution, would have run into trouble a lot sooner even if they had kept their population under control, but they didn't. Human populations tend to grow up to the limit of their resources. Indeed, they frequently grow beyond them.

First, the Europeans at home and in their overseas colonies went through one of the greatest population booms in history, growing from 20 percent of the world's population in 1600 to about 35 percent by 1900. Most of their descendants (together with a few other people like the Japanese and the Koreans) live in developed societies, so about one billion people, the equivalent of the entire world's population in 1800, now consume food, burn fossil fuels and emit greenhouse gases at a fully industrialized rate. But second, and more importantly, the public-health measures that had allowed the population growth rates to soar in those countries soon spread to the rest of the world, triggering a comparable boom there, and so there are now more than five billion other people in the world as well. Over half of them live in countries where very high economic growth rates (6–10 percent annually) are now rapidly shifting the population towards late-industrial patterns of consumption and emission.

They cannot all get there: key resources (including oil and gas) are not sufficient to sustain three or four billion people in the current "developed world" lifestyle. Some scaled-down, heavily modified version of that lifestyle might be possible for such large numbers if it were attempted gradually and with great care over a long period of time, but the present headlong dash for growth will short-circuit the process by hastening the onset of an acute climate crisis long before the goal is reached. And the first and worst manifestation of that crisis will be in the world's food supply.

> [A rise of] one to two degrees would probably leave global food supply more or less okay. You would have some shifting (of food production) toward the higher-latitude countries and away from the countries that are close to the equator, where temperatures are already at critical thresholds. It's really the two to three to four degrees and more warming that can be particularly devastating. You can get there by the end of this century, and if you do get to that, then you're facing losses

> of output potential of something of the order of 20–25 percent in Africa and Latin America, 30 percent or more in India.
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> Although that's partially compensated by increased potential in some of the northern industrial countries, it would clearly be problematical. That's especially true if you don't have the benefit of what's called "carbon fertilisation": the fact that there's more carbon dioxide in the atmosphere, and carbon dioxide is an input into photosynthesis, so in principle you can get some offset from that . . . [But there is a] question of whether the laboratory tests, which do confirm higher yields, are realistic. Do they take account of open-air conditions? Do they take account of the need for other nutrients that go with the carbon? And basically the more recent experiments in the open air suggest that the earlier estimates had been exaggerated.
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> —William Cline, senior fellow,
> Peterson Institute for International Economics

All the other impacts of climate change—rising sea levels, bigger hurricanes and storm surges, the migration towards the poles of diseases now confined to the tropics—will arrive on schedule or before, but nothing matters as much to human beings as the food supply. Stop eating, and you will reduce your carbon footprint to zero in a matter of months. A higher concentration of carbon dioxide in the atmosphere probably has minimal positive effect on grain yields even in the temperate parts of the world, and all the other impacts of global warming on food production are bad.

Higher temperatures will have a disastrous impact on food crops in parts of the world where the average temperature during the growing season is already close to the maximum at which the plants can germinate. We have selected and crossbred those plants over ten thousand years to be the best possible match for the existing climatic conditions, and they have very limited ranges of tolerance for different environments. For example, recent research at the University of Reading revealed that two of the most widely grown varieties of rice, lowland indica and upland japonica, were both very vulnerable to high temperatures during flowering (anthesis and fertilization), with the plants being largely sterile (i.e. bearing few grains of rice) if the temperature exceeded thirty-five degrees Celsius for more than an hour during that period. In many tropical countries, there are already extended periods during the growing season when the temperature is only a degree or two below that level. More generally, experiments in the Philippines suggest that rice yields fall by 15 percent with each one degree rise in average temperature during the growing season. We can (and should) launch crash programmes to breed new strains of key crops that are more tolerant of extreme heat, but we cannot be sure of success. We can be pretty sure that yields will be lower, even if we are successful.

A second problem is soil moisture. On average, there will be more rainfall on a warmer planet, since evaporation from the oceans will increase, but even areas that benefit from increased rain will also be suffering from higher rates of evaporation from the soil. As William Cline pointed out in the interview cited above, "the availability of soil moisture is the result of a race between faster evaporation as you get higher temperatures and, in some areas, at least, greater rainfall. The evaporation goes up very rapidly as you get higher temperatures, and so that race is basically lost in lots of countries that are closer to the equator, where there are already problems with the dry conditions." Places such as most of Africa, much of Central and South America, the entire Middle East, and a great deal of Asia.

So the tropics and the subtropics get hit first and worst, but it is generally assumed that temperate-zone agriculture will actually benefit from a little warming. Maybe increased productivity in the mid- and high latitudes will compensate for the fall in food production closer to the equator, or so it is hoped, but there are three unanswered questions here. One is whether this predicted increase in food production in the temperate latitudes could possibly be enough to cover the loss of tropical production *plus* the growing global population (another two-and-a-half billion by 2050?) *and* the rapidly rising per capita consumption of meat and dairy products (whose production eats up vast quantities of grain) in the fast-growing economies of Asia. A second is the question of how that hypothetical excess food, grown in the rich, high-cost economies of the developed world, actually makes its way into the mouths of the hungry poor in the tropics. Who's going to pay for it? And the third and biggest question is whether the prediction that food production will increase in the temperate zone, at least while we are still on the lower slopes of the global warming curve, is actually true.

Everybody agrees that, in a warmer world, with increased evaporation from the oceans, there will be more rainfall overall. The problem is that most of the rainfall may be in the wrong places. There will be plenty in the higher latitudes, but a good deal less in the mid-latitudes where we grow most of the world's grain. The breadbaskets of the planet—the American Midwest, the north Indian plain, the Australian wheatlands, the Mediterranean Basin, and so on—are likely to take big hits in terms of reduced rainfall and lower crop yields.

The reason for this is an atmospheric circulation pattern called the "Hadley cells." What drives this circulation pattern is the fact that warm, moist air is continuously rising at the equator—moist because there is high evaporation from the warm ocean surface, and rising because that is what warm air does. As it rises, however, it cools—the temperature drops three degrees Celsius with every thousand metres of altitude—and cool air cannot hold nearly as much water as warm air, so the moisture comes out in the form of tropical downpours. High above the equatorial regions, therefore, there is a constantly replenished layer of chilled, recently dried air—which is then pushed away, to both the north and the south, by more warm, moist air rising from below. This cold, dry air comes back down to the Earth's surface some 2,500 to 3,500 kilometres away from the equator, and as it descends it heats up due to the increasing pressure (a process known as "adiabatic heating"). When it hits the surface, it is both hot and dry. This is what causes the world's deserts.

The deserts are not randomly distributed around the planet. Most of them are arranged in two bands of desert girdling the planet north and south of the equator, precisely at the latitude where the Hadley cells bring their hot, dry air down onto the surface. (Then the circulation closes the loop by flowing back towards the equator on the surface—which is what gives us the "trade winds.")

Spin an old-fashioned globe mounted on a spindle and you will see the desert zones of the world blur into two yellow bands at around latitude twenty-five degrees North and latitude twenty-five degrees South. The Northern Hemisphere deserts caused by the Hadley cells, moving from west to east, are the Sahara Desert in Africa, the Arabian Desert in the Middle East, the Thar Desert in western India and southern Pakistan, and the Great Southwestern Desert in the United States and its Mexican counterpart. They are all along the same line of latitude. The similar band in the Southern Hemisphere (where there is much less land and much more sea) begins with the Kalahari Desert in southern Africa, continues through the great Australian Desert, and finishes up in the deserts of Peru and northern Chile.

Most of the world's richest breadbaskets, the places that are blessed with plenty of sunshine, long growing seasons and lots of rain, are located just a little further away from the equator than these deserts. Australia's wheat belt is immediately south of the desert all the way across the county from Perth to the Murray-Darling Basin. The traditional granaries of the Mediterranean countries and the Fertile Crescent are just north of the Saharan and Arabian deserts. The American Midwest is just north (and a bit to the east) of the great deserts of southwestern U.S. and northern Mexico. It would be disastrous if those desert bands expanded, encroaching on the breadbaskets—and that is exactly what will happen under almost any global heating scenario. Higher temperatures mean more energy in the system, and the Hadley cells expand, encroaching on the land that is now farmland. It doesn't all turn into desert, of course, but we can expect rainfall to drop by 25 percent, 50 percent, even 75 percent over the breadbaskets, depending on the specific region and the amount of heating that we are experiencing. That is not a happy thought, for we don't have much margin for error with the food supply.

Over the past sixty years, we have re-enacted the miracle of the loaves and fishes: we are now feeding three times as many people off roughly the same amount of land. In 1945, the world's population was just over two billion people, only double what it had been in 1800. In the ensuing sixty-odd years, it has more than tripled to 6.7 billion—and the vast majority of them have enough food to eat. Yet no more than 10 percent of the land we grow food on now was not already being farmed in 1945: human beings have been farmers for a very long time, and most promising farmland was brought under the plow a long time ago. Essentially, we have tripled the yield on the existing farmland.

This miracle owes something to the famous "green revolution," the biologically engineered new strains of familiar crops that were more drought-resistant, higher-yielding, more salt- and insect- and disease-resistant. But it owes more to brute force: in the postwar decades, we threw fossil fuels at the problem in a big way. Indeed, in a sense we are now eating fossil fuels: the amount of fertilizer we put on the land has increased more than tenfold since 1945, and the feedstock for nitrogen fertilizers is ammonia, which we obtain from natural gas. This shitload of fertilizer had dramatic results in terms of increased yield over the last half-century, but it is now hitting diminishing returns: not only does putting even more fertilizer on the land fail to raise yields as much as before, but even our current levels of fertilizer use are damaging the land and the water systems in a variety of ways.

We are also irrigating three times as much land as was irrigated in 1945. It still amounts to only 15 percent of the world's cropland, but it now accounts for 40 percent of total food-crop production. Did we discover a lot of new rivers after 1945? Of course not. Most of the new irrigated land depends on pumping water up from aquifers deep underground—in some cases a thousand metres underground. Once again, it is fossil fuels that drive the pumps that provide the water, and once again we are hitting diminishing returns. Many of the aquifers were filled millions of years ago and no longer have any natural connection with the surface, so they do not recharge: once all their water has been pumped up, that's the end of it. Others do refill gradually over time, but almost all of those are also being pumped at unsustainable rates.

In much of the world we also mechanized agriculture (more fossil fuels), although it is arguable that mechanized agriculture yields less per acre, on average, than the intensive cultivation and daily attention that a peasant farmer's family would bring to the same acre. At any rate, the six-and-a-half billion are being fed, if not in a very sustainable way. However, both the natural gas that makes the fertilizer and the oil that fuels the farm machinery and irrigation pumps are depleting as fast as the underground water. World grain production, which grew at an average of 2.5 percent annually through the half-century after 1950, has now flatlined for some years. The population is still growing, and there are no more green revolution tricks left in the box. The recently revived claims that genetically modified crops will help to "fight world hunger" are as false and cynical as ever: GM food crops that have been engineered for drought resistance, salt tolerance, increased yield, etc., simply do not exist. Perhaps one day such wonder-crops will be developed, but all the commercially available

GM crops have simply been engineered to make them resistant to the effects of certain patent herbicides and insecticides, so that more of those products can be sold to farmers and dumped on the land. We would have a major food supply problem even if the climate remained stable.

It is true that birth rates have dropped in most countries, below replacement level in many, but there is still a lot of population growth left in the system because human beings are not salmon. We do not spawn and die. We have our children and live on for many decades afterwards, so the net population continues to grow for at least a generation and a half after the birth rate drops below replacement level. For example, I and my four brothers and sisters all married, and between us we have ten children, so technically we dipped slightly below replacement level (2.2 children per completed family) in our own generation. However, we ourselves are all still alive many years later, so there are twenty people where there once were ten. Indeed, there are already six grandchildren, and still my own generation lives on. This is happening worldwide, so the global population is predicted to continue growing, at a diminishing rate, until it stabilizes at 8.5 or 9 billion people in the latter half of this century.

But, it is extremely unlikely that there will ever be 9 billion human beings on this planet. It's not just that there is no obvious way to feed the next two-and-a-half billion. In the relatively near future, global heating is going to start depriving us of a large and steadily increasing portion of the food supply that supports the present 6.7 billion. There will be famines, and a great many people will die. So while we work frantically to get our greenhouse-gas emissions down to zero, we also have to find ways of avoiding the wars that would increase the deaths by an order of magnitude—wars that would also cripple our attempts to avert the runaway climate change that would cause megadeaths later on.

History shows, archaeology shows, that humans grow their population until they reach the carrying capacity of their environment . . . They've always done this: hunters and gatherers have done it, early farmers have done it, everybody in the world has done it. And when you reach the carrying capacity, in part because things are never constant . . . it doesn't take long before the climate gets you. The climate gets just a little bit worse, and suddenly you run out of resources, and you compete with your neighbours to get those resources so you don't starve. . . .

Humans have never been able to live comfortably within the carrying capacity. They've never been able to restrict their growth so that they stayed well below it, below it enough so that when the climate turns a little bit against them, it doesn't have a major effect. They've never been able to do this . . . The other thing that comes out of looking at the deep past is that this process can sometimes take a couple of hundred years. Your growth can be slow, the climate can get better and better for a while, you can sometimes let this go on for maybe two, maybe even three hundred years. I can't find any place in the world where it ever went longer than that without there being a crisis that resulted in warfare, depopulation, starvation, etc., . . .

If you want to get scared—we are now in a cycle that you could argue started with the Industrial Revolution in the early 1800s. We're now more than two hundred years into this. We could be [just] one more example of the same phenomenon, but we think that somehow it's different this time . . . Since the 1800s our population has grown four- or fivefold, and it's quite conceivable that you could have a crash right back to where you were. When things are good, the

> population grows, [and] we sow the seeds of our own crisis.
>
> —Stephen LeBlanc, director of collections,
> Peabody Museum of Archaeology and Ethnology,
> Harvard University

We are clearly operating quite close to the limit of global carrying capacity with existing food-production technologies, but the rapid population growth of the past two centuries is not inevitably destined to end in a population crash. There is still a certain cushion of safety between us and too few calories per person worldwide (especially if we were to consume more of the grain we grow directly, rather than feeding it to animals to make meat). An end to the current population surge is possible *without* the intervention of famine. It is just not guaranteed.

On an optimistic reading of the statistical trends, the world's population is heading for stabilization at eight or nine times the pre-industrial level by the mid-to-late twenty-first century. That is rather a lot of people: we and our domestic animals would then account for more than half the total weight of the land-dwelling mammals of the planet. But it is probably within the capacity of current food production techniques to feed so many people, at least for some centuries, *provided* that this dense population was only faced by the sort of modest, local cyclical fluctuation in climate that destroyed, for example, the Anasazi societies of what is now the U.S. Southwest in the thirteenth century. Climatic changes on that historically familiar scale would not be global, they wouldn't be permanent, and help from outside could sustain stricken regions until the crisis passed.

The catch, however, is that this huge population boom was only made possible by the exploitation of fossil fuels, whose burning has produced as a by-product greenhouse gases that are now changing the global climate on a scale at least an order of magnitude larger than the fluctuations of the past. Indeed, what we face now is not fluctuations at all, but rather the risk of accelerating, irreversible changes in the whole pattern of the world's climates—and most of those changes would have large negative impacts on food production. So maybe we don't escape from that three-hundred-year cycle after all—and the indisputable fact is that people (or at least people in the small-scale societies that anthropologists study) always attack the neighbours before they starve. Would that be true of large, developed societies too? How badly do we want to find out? Because even some relatively rich countries are going to have trouble feeding their people as global warming progresses, while some countries nearby will still have food. The pain will be unequally shared, at least in the early phases of the crisis, and it is this business of winners and losers that poses the greatest threat to global order.

Nearer to the equator, most countries will be in severe trouble: a recent study done by the Indian think tank Integrated Research and Action for Development (IRADe) concluded that a rise of only two degrees Celsius in global average temperature would cut Indian food production by 25 percent. Since India's one billion people grow just enough food to feed themselves now, that is the equivalent of around 250 million Indians with nothing to eat—and it is unlikely that they would be able to buy food from outside, since, in any global heating scenario, most regions of the world that now have a substantial food surplus will be hard hit as well.

India's food situation at two degrees Celsius hotter is desperate enough, but it does not begin to compare with the plight of Bangladesh, where the southern third of the country—home to sixty million people—would be literally disappearing beneath the waves due to sea-level rise. Relatively few people in Bangladesh understand yet why their country is vanishing from under their feet, but they will. They will also understand who caused this "climatic genocide," as

Bangladeshi climate scientist Atiq Rahman calls it. Their bitterness will be very great.

> This is the ground zero of global warming. There is no question that this is being caused primarily by human action. This is way outside natural variation. If you really want people in the West to understand the effect they are having here, it's simple. From now on, we need to have a system where, for every 10,000 tonnes of carbon you emit, you have to take a Bangladeshi family to live with you. It is your responsibility.
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> —Atiq Rahman, executive director,
> Bangladesh Centre for Advanced Studies,
> interviewed in *The Independent*, June 20, 2008.

It is just ugly now, but later on it could get very dangerous across a lot of Asia. Pakistan, for example, whose vast area of irrigated land depends mainly on rivers that rise in India, is immensely vulnerable if India decides that its own needs come first. This is one part of the world where wars over water really are possible—and both India and Pakistan are already nuclear weapons powers. Bangladesh could be one, too, in a few years, if it really wanted to.

Africa will be the continent that takes the biggest hit from climate change, and it is already home to more than half the wars in the world. The impacts of climate change will probably trigger many more wars, but the brutal truth is that most conflicts in Africa do not affect the rest of the world. The Middle East is a very different case, but in this region climate-related changes are likely to exacerbate existing confrontations rather than create entirely new ones, so they need not be considered further at this point. The new and unfamiliar lines of potential fracture run between the northernmost tier of the major powers and the tier immediately to the south. Since these are developed countries, with very large industrial, technological and organizational resources at their command—and the ability to acquire nuclear weapons in fairly short order if they do not already possess them—it is the possible conflicts between them that pose the greatest threat.

In developed countries very far away from the equator, most farming areas will continue to receive adequate rainfall, and may even be a net beneficiary of the warmer temperatures. In particular, countries where the current northerly limit for agriculture is largely determined by the length of the growing season may find that the farming frontier has moved several hundred kilometres northwards as the number of consecutive frost-free days per year in those regions reaches the threshold needed for grain growing: as few as ninety days are enough in the really high northerly regions, where you can easily have sixteen hours of sunshine per day in the high-latitude summer. The big winners in this geographical lottery will probably be Scandinavia and Russia. Canada may also benefit in the early stages of warming, but not in the later period. (There are no comparable land masses at these latitudes in the Southern Hemisphere.)

In the other countries in the mid-latitudes of the Northern Hemisphere, it is a more complicated picture, but it generally resolves itself along a north-south axis. The more northerly tier of these countries, including the British Isles, most of France, the Low Countries, Germany, Scandinavia, Poland, Russia, Korea and Japan, and the densely populated parts of Canada, will continue to receive adequate rainfall, and these countries will generally be able to feed themselves. The more southerly countries, however, are likely to suffer severe declines in annual rainfall thanks to the expansion of the Hadley cells, resulting, in many cases, in recurrent or permanent drought. The affected regions would include Mexico, the Central American and Caribbean states, both sides of the Mediterranean, the entire Middle East, and the main grain-growing regions of Pakistan and India. Their main export, a generation hence, may be refugees.

Both of the world's greatest powers are also in the northern mid-latitudes, but their sheer size makes matters more complicated, for they straddle several of the zones mentioned above. For a variety of unrelated reasons, China is the big loser. While its most northerly region, Manchuria, comparable in latitude to the New England states in the United States, should continue to receive adequate rainfall at plus-two degrees Celsius, the north Chinese plain, where the country grows most of its wheat, will not: the monsoon that delivers the summer rainfall over most of that region is already beginning to fail, and in the longer run, the volume of flow in the Huang He (Yellow River) will be affected as well. To make matters worse, the shallow aquifer that underlies much of that region has already been pumped dry, and the deep aquifer is going fast. Farther south, where the main grain crop is rice, the glaciers and snowpack in the high Tibetan Plateau that feed the Yangtze and other major rivers are melting. When they are gone, the rivers will become more seasonal, and will contain less water in the summer months, when it is most needed.

> Northern Eurasian stability could . . . be substantially affected by China's need to resettle many tens, even hundreds of millions from its flooding southern coasts. China has never recognized many of the Czarist appropriations of Chinese territory, and Siberia may be more agriculturally productive after a 5 to 6 degree C rise in temperature, adding another attractive feature to a region rich in oil, gas and minerals. A small Russian population might have substantial difficulty preventing China from asserting control over much of Siberia and the Russian Far East. The probability of conflict between two destabilized nuclear powers would seem high.
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> —R. James Woolsey, Jr., describing the security implications of his "catastrophic" one-hundred-year scenario in *The Age of Consequences,* November 2007

The United States is a harder case to call. It will probably suffer huge losses to its food production on the high plains west of the Mississippi River, where the rainfall will be diminishing at the same time as the giant Ogallala aquifer that provides irrigation water for the entire region is finally pumped dry. The Central Valley of California, which accounts for one-quarter of the food grown for human consumption in the United States, will face grave difficulties if the rivers that are fed by the snowpack on the mountains become seasonal (winter only): at two degrees Celsius hotter, much of the snow that now falls on the mountains in winter will fall as rain instead and run off immediately, leaving the rivers largely dry in summer. Nevertheless, the United States may still have enough good agricultural land in the "Old Northwest" and within a few hundred kilometres of the sea along the eastern seaboard, the Gulf coast, and in the Pacific Northwest to feed its own population, which is forecast to be four hundred million by 2050.

It is unlikely, however, that even the U.S. will still be in the food-exporting business once global heating reaches two degrees Celsius. Except for quite limited surpluses in Russia, Scandinavia, and (maybe) Canada, nobody will be exporting food. If you cannot produce enough at home, then your people will just have to starve.

This is not just a formula for famine; it is also a formula for war. All around the world, countries facing mass starvation will be just a bit closer to the equator than countries that can still feed their people, and some of the countries on the losing side will be sufficiently developed to make their unhappiness with this outcome felt. (People always raid before they starve.) To make matters worse, it will not escape notice that the countries that suffer least from the changing climate are, in most cases, the ones that industrialized first, and that are responsible for most of the emissions that have set this lethal process in motion.

The outlook is not promising. The twenty years that have slid by with little action since NASA (National Aeronautics and

Space Administration) scientist James Hansen gave his famous warning about climate change to the U.S. Congress in 1988 will not come back, and realistic people understand that it may be too late to avoid some truly unpleasant consequences no matter how hard we try to make up for the lost time. Concerted global action to cut emissions by, say, 80 percent in the next twenty years would avert the worst of the changes that lie in wait for us, but that would require the abandonment of "politics as usual." Moreover, the deeper we get into the food shortages attendant on global heating, the more difficult it will be to make international deals of any kind, though only global deals can save us. Once we hit mass famine, mass migrations, and widespread war, the game is lost, and the only rule is *sauve qui peut.* Every man for himself.

China is particularly worrying, as the country's insatiable need for energy imports, together with the general unsustainability of its present pattern of headlong economic growth (12 percent in 2007), mean that it may be heading for a crash: political and social upheavals may threaten internal stability, and paralyze the government's ability to make deals about greenhouse-gas reductions and carry them through. The Chinese Communist regime itself often warns that such upheavals could break the country's unity. That would leave behind squabbling fragments, with which it would be impossible for the rest of the world to make viable deals on curbing emissions.

But it is still too early in the game for despair. People and countries have in the past found ways to cooperate—not perfectly, perhaps, but well enough to avoid ultimate disaster. The most recent example (for which we are shamefully ungrateful) was the avoidance of a hemisphere-killing nuclear exchange during the forty years of the Cold War. Luck played some part in our escape, no doubt, but so did the dedicated efforts of several generations of people who, at the time, saw themselves on different sides of the barrier: those who opposed nuclear weapons altogether, and those who commanded them and kept them in check. Most people are not stupid, and very few are suicidal. So, with this precedent in mind, what are the chances that we can do it again—that is, make it all the way through the twenty-first century without tumbling into runaway global heating and a massive dieback of the human population?

The country that has taken that question most seriously is Germany, where the government has promised to cut greenhouse-gas emissions by 40 percent by 2020, a target that dwarfs anybody else's. (And Germany is, by the way, a cloudy northern country with relatively little in the way of wind.) Dr. Hans-Joachim Schellnhuber is the director of the Potsdam Institute for Climate Impact Research and climate change adviser to the German Chancellor, Angela Merkel.

> Here in Germany we feel that if we can confine global warming to two degrees Celsius above pre-industrial level—that's now the official goal of the European Union, and was heavily supported by Chancellor Merkel—then we would be in a position to avoid what we call "dangerous" climatic change. We cannot be entirely sure. There are these tipping points out there (which is a special field of my own research), but we would at least have a fair chance to avoid the things which turn out to be unmanageable. Two degrees warming would still mean a different world, but probably we would keep climate chaos at bay, at least.
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> So let's focus on these two degrees first. In order to achieve that, we would have to reduce greenhouse-gas emissions by 2100 to almost zero. By 2050, we would have to reduce emissions at the very least by 50 percent globally as compared to 1990. That would mean that the United States, for example, would have to reduce by 2050 by 90 percent, Germany and the U.K. by 80 percent. If you follow that line, Germany with the 40 percent reduction by 2020 would be on track, actually, but it

> would have to go into an 80 percent reduction by 2050.
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> Now there are some people, like Jim Hansen at NASA, who say we have to stabilize GHG [greenhouse-gas] concentration at 400 parts per million . . . I think 450 parts per million is—not a safe level, but a tolerable level. I'm concerned if people in the U.K. say that 550 parts per million is okay, because that would mean—best guess—at least three degrees of warming. Since the difference between an ice age and a warm age is just five degrees, that would be 60 percent of that distance, but we are in a warm age already, so it would mean that we would enter a hot age. That's not acceptable.
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> I think the 450 parts per million target, also known as the two degrees limit, is at least a good working hypothesis. If we go down this line of 40 percent cuts by 2020 and 80 percent by 2050, then we would develop an appetite for avoiding fossil fuels. Once we learn that we can change the energy system without becoming poorer, then I think we will do even more. We will become more and more ambitious as we go. That would be my strategy.

This 450 parts per million target—also known as the +2 degrees Celsius limit, although it only offers a 50 percent chance of staying below that temperature—has been the official "never-exceed" target of the European Union for several years. More recently, at the G8 Summit of July 2009, the same target was adopted by all the major developed countries (the United States, Russia, Japan, Germany, Britain, France, Italy and Canada), by the Big Five developing countries (China, India, Brazil, Mexico and South Africa) and by four other major emitters (Australia, Indonesia, South Korea and the European Union). Altogether, these countries are home to more than half of the human race. Alas, 450 parts per million is no longer seen by leading-edge scientists as the right target, although the usual cultural lag means that most of the policy-makers have not realized it yet.

The climate scientists who espoused the 450 parts per million limit some years ago based their choice partly on the state of the science at that time, but also on the political calculation that this was the most ambitious target they could advocate without being treated as lunatics by the "practical" people who run our political and industrial systems. After all, we were already in the 380s, with high-speed global economic growth *adding* more than two parts per million to the total each year. How were you going to stop that juggernaut short of 450 parts per million? Indeed, how were you even going to stop it there? You have to be a realist. But even then James Hansen was saying that is would really be unwise to go beyond 400 parts per million. Now he's saying the safe limit is really more like 350 parts per million (which you can only see in the rear-view mirror).

The great uncertainty in all estimates of future climate change is how much temperature change will be caused by a given amount of extra carbon dioxide in the atmosphere. This is complicated by the fact that climate change is non-linear (e.g. the fact that the world warmed about 5 degrees Celsius between the depth of the Last Glacial Maximum 20,000 years ago and the onset of stable warm conditions about 12,000 years ago, while the carbon dioxide in the atmosphere increased from 180 parts per million to 280 parts per million, does not necessarily mean that the rise from 280 parts per million to 390 parts per million over the past two hundred years will bring a further warming of five degrees Celsius).

Moreover, whatever warming there is will be divided between fast-feedback climate effects occurring on a scale of years or decades (increased evaporation, changes in cloud cover, melting of polar sea ice, possible releases of methane from permafrost, etc.), and slow-feedback effects like the melting of the glaciers on Greenland and Antarctica, followed by the spread of dark, sunlight-absorbing plant cover over large land areas previous covered with highly reflective glaciers, that operate on a time-scale of decades to centuries or even longer. For these and other reasons, it has remained difficult to reach a consensus on exactly what level of carbon dioxide in the atmosphere creates a grave danger of irreversible warming big enough to take us right out of the Holocene, the interglacial period of stable climate in which human civilization has grown and our number have increased almost a thousandfold. Decades of more and more sophisticated climate models have helped greatly, but the level of uncertainty remains—so in a recent scientific paper James Hansen and others took a quite different approach to the problem.

> Paleoclimate data shows that climate sensitivity is approximately 3 degrees Celsius for doubled carbon dioxide, including only fast feedback processes . . . [I]ncluding slow feedback processes, [it] is approximately 6 degrees Celsius for doubled carbon dioxide for the range of climate states between glacial conditions and ice-free Antarctica. Decreasing carbon dioxide was the main cause of a cooling trend that began 50 million years ago, large scale glaciation occurring when carbon dioxide fell to [425 parts per million], a level that will be exceeded within decades, barring prompt policy changes. If humanity wishes to preserve a planet similar to that on which civilization developed . . . carbon dioxide will need to be reduced from its current 385 parts per million to at most 350 parts per million. . . . If the present overshoot of this target carbon dioxide is not brief, there is a possibility of seeding irreversible catastrophic effects.
>
> Abstract of "Target Atmospheric Co_2: Where Should Humanity Aim?" by James Hansen, Makiko Sato, Pushker Kharecha, David Beerling, Valerie Masson-Delmotte, Mark Pagani, Maureen Raymo, Dana L. Royer and James C. Zachos, published at http://www.columbia.edu/~jehl/2008/target/co2-20080407.pdf

Rather than modelling today's and tomorrow's climate, Hansen and his colleagues looked at ancient climates and the transitions between them, to try to work out the relationship between changes in carbon dioxide concentrations and changes in average global temperature. Their first conclusion, drawing on reasonably reliable data for the recent Pleistocene era, was that the relationship between carbon dioxide and temperature is not all that non-linear after all, at least for the range of climates between deep glaciation (glaciers covering not only Antarctica but much of the northern hemisphere) and a much warmer, substantially ice-free world where the sea level is around 150 metres higher. At any point along that range of climates, doubling the amount of carbon dioxide in the atmosphere gets you three degrees Celsius of fast-feedback warming, followed by a further three degrees Celsius of slow-feedback warming. This is not happy news, as it means that there is no fortuitous non-linear escape hatch. The data from the deep past do not allow Hansen et al. to estimate how long it would take for the fast-feedback warming to occur in our current context, or how much longer it would take for the slow-feedback changes to produce the rest of the warming. In the deep past, the changes in carbon dioxide levels in the atmosphere, mostly driven by geological events like volcanism or weathering of rocks, were happening hundreds or thousands of times more slowly than the current anthropogenic changes, so we cannot look to the past for guidance on those questions. In particular, the ancient data give us no indication of the role, if any, that feedback mechanisms like rapid and massive releases of methane gas might play in determining the pace of the warming.

That's a pity, because this information may be of critical importance to us in the relatively near future: big methane releases could accelerate the warming well beyond what is predicted to happen from the accumulation of carbon dioxide alone. But methane releases are generally just an accelerant to global warming, not a fundamental factor, since methane lasts a relatively short time in the atmosphere. Ultimate outcomes are driven by carbon dioxide concentrations, and the key conclusion of Hansen and his colleagues was that if we double the carbon dioxide concentration in the atmosphere, we get the full six degrees Celsius of warming eventually.

The other conclusion of the Hansen team is about the carbon dioxide level that would initiate the irreversible melting of the Antarctic ice cap. There have been thick ice caps at the South Pole before, but so long ago that the data on what was happening in the atmosphere at the time when they finally melted is sparse to non-existent. However, we do have fairly reliable data for what was happening in the atmosphere when the current Antarctic ice cap began to grow in a previously ice-free world, some 35 million years ago. The concentration of carbon dioxide in the atmosphere at that time was 425 parts per million, with a margin of error of plus or minus 75 parts per million. If that was the point at which the Antarctic began to freeze when the carbon dioxide concentration was on the way down, it is a fairly safe bet that that is also the point when the last ice would melt in the Antarctic on the way back up—not right away, of course, but after all the slow-feedback warming has run its course. And that would be the last ice in the world: the Greenland ice cap and the glaciers of the high northern latitudes came later when the temperature and the carbon dioxide concentration were on their way down, so they would be gone earlier on the way back up.

These are numbers that we have to take with deadly seriousness. Allowing for that big margin of error (75 parts per million plus or minus), we can nevertheless be fairly sure that all the ice on the planet will eventually melt if the concentration of carbon dioxide in the atmosphere remains at some point between 350 parts per million and 500 parts per million for any lengthy period of time. We are already well past 350 parts per million, so there is a serious possibility that we are headed for a greenhouse planet even if we stop the increase right now—which is, of course, impossible. We'll be very lucky if we can stop the rise before we reach the 450 parts per million level that the world's major powers have recently adopted as their "never-exceed" ceiling, but that level gives a very high probability that all the ice eventually melts. Therefore, James Hansen and his colleagues now argue that our target should be not 450 parts per million, but 350 parts per million. Then we would probably be safe. According to Hansen:

> You know, the logical thing, if you want to keep the climate similar to that of the Holocene, you've probably got to keep the carbon dioxide not too different than what it was in the Holocene, which means on the order of 300 parts per million . . . To figure out the optimum is going to take a while, but the fundamental thing about the 350 [parts per million target], and the reason that it completely changes the ball-game, is that it's less than we have now. Even if the optimum turns out to be 325 or 300 or something else, we've go to go through 350 to get there. So we know the direction now that we've got to go, and it's fundamentally different. It means that we really have to start to act almost immediately.
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> Even if we cut off the coal emissions . . . carbon dioxide would get up to at least 400, maybe 425, and then we're going to have to draw it down, and we're almost certainly going to have to do it within decades . . . So how can you draw down the carbon dioxide, and how much can you draw it down?
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> We have a pretty good idea. You can sequester carbon in forests and in the soil. In both cases we're doing a bad job [at the moment]. We're actually losing carbon to the atmosphere from the soil and from the forests we cut down. We could improve our practices. In the case of agriculture, you can work bio-char, charcoal, into the soil, and use no-till agricultural practices in more areas

> where it would work well, and that allows carbon to be stored in the soil instead of escaping to the atmosphere. And we could re-forest areas where there's degraded land now that's not being used even for agriculture; we could store a lot of carbon in those trees. If you look at this quantitatively, you could probably store about 50 parts per million of carbon dioxide that way. But if we just continue to burn coal, we're going to be at 450, 500, 600 parts per million or larger, and then I don't see any way you can solve it by means of these fairly natural solutions of trying to re-forest and improve the productivity of the soil.
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> —James Hansen, director,
> NASA Goddard Institute for Space Studies

There is no need to despair. The slow-feedback effects take a long time to work their way through the climate system, and if we could manage to get the carbon dioxide concentration back down to a safe level before they have run their course, they might be stopped in their tracks. As Hansen et al. put it in their paper:

> A point of no return can be avoided, even if the tipping level [which puts us on course for an ice-free world] is temporarily exceeded. Ocean and ice-sheet inertia permit overshoot, provided the [concentration of carbon dioxide] is returned below the tipping level before initiating irreversible dynamic change . . . However, if overshoot is in place for centuries, the thermal perturbation will so penetrate the ocean that recovery without dramatic effects, such as ice-sheet disintegration, becomes unlikely.

The real, long-term target is 350 parts per million or lower, if we want the Holocene to last into the indefinite future, but for the remainder of this book I am going to revert to the 450 parts per million ceiling that has become common currency among most of those who are involved in climate change issues. If we manage to stop the rise in the carbon dioxide concentration at or not far beyond that figure, then we must immediately begin the equally urgent and arduous task of getting it back down to a much lower level that is safe for the long term, but one step at a time will have to suffice. I suspect that few now alive will see the day when we seriously start work on bringing the concentration back down to 350, so let us focus here on how to stop it rising past 450.

One hopeful recent development is that the U.S. foreign-policy establishment and the military are both now fully alert to the threat posed by climate change. Even if Senator John McCain had become president in January 2009 instead of Senator Barack Obama, the long reign of climate-change denial in the White House would have come to an end: by the end of the election campaign, both men were promising 80 percent cuts in American greenhouse-gas emissions by 2050. President Obama's appointments to key posts like energy secretary (Stephen Chu) and chief scientific adviser (John Holdren) indicated that he really does grasp the nature and scale of the problem. (If he knows what they really think, and he appointed them anyway, that tells us what *he* thinks.) But the question remains: will this be enough to transform the global political dynamic and make a comprehensive agreement on curbing greenhouse-gas emissions possible?

It might be, if it were just the old industrial nations who had to curb their emissions drastically in order to avoid runaway climate change. However, they are not alone in the world, and will not long remain the only industrialized countries.

Most of the older industrialized countries have not increased their emissions significantly since 1990. Their current pattern of energy use is so profligate that they could cut consumption by at least 20 percent without suffering dramatic changes in their lifestyles. With greater effort and a little sacrifice, conservation could cut their energy requirements by 30 percent, and their greenhouse-gas emissions by almost as much. But cuts in greenhouse-gas emissions almost three times that deep are needed by 2050 if we are to avoid soaring past 450 parts per million of carbon dioxide, which means that not only the demand side of the equation but also the supply side must be changed. That is much harder to do.

This is an energy-intensive civilization built mainly on the availability of plentiful and cheap fossil fuels, and it cannot sustain anything like its present numbers without continuing to use enormous amounts of energy. Switching from fossil fuels to non-carbon sources for most of that energy is theoretically possible, but doing it in a relatively short period of time, without ever interrupting the supply, is akin to changing the engine, the driveshaft and all four wheels of a moving car without ever stopping it.

There is also the political problem that the alternative-energy sources may have to include a large-scale return to nuclear-power generation. Hydro is good, but, in most countries, most of the good sites have already been developed. Tidal power is promising for some countries, but is still in development. Wind and waves and sunshine are all excellent carbon-free sources of power, but there are times when the wind does not blow and the sun does not shine. This leads us directly to the "base load" concept of electricity, which argues that there is a need for some large, non-fluctuating source of power to stabilize the system—and that the only substitute for fossil-fired power plants that is technologically mature and immediately available is nuclear power. Even to mention nuclear power causes fury in a large section of the environmental community, however, and there is likely to be a political struggle over nuclear power that will split the green movement and perhaps the general public in almost every Western country. The simplest way to stop the fight would be to agree that nuclear power stations may be built so long as they do not require subsidies (since no nuclear power plant has ever been built without subsidies), but perhaps that is too simple.

If agreement on alternatives can be achieved fast enough, the developed countries will probably be able to replace most of their power-generating plants with non-fossil sources in as little as two decades. Combined with conservation measures, that would achieve the emissions cuts that most climate-change experts deem necessary, if we are to avoid disastrous changes later in the century. After all, the design lifetime of most power plants we build now is forty or fifty years, so we are, in practice, committed to replacing our entire power-generating capacity with new plants every half-century anyway. Doing it in twenty years is obviously a big step up from normal service, but it is *not* an unimaginably great change. If the demand is present, so will be the supply.

Unfortunately, it is not just the older industrial countries that must curb their emissions. Most of the growth in emissions at present is actually in the newly industrializing countries of Asia and Latin America. China's emissions are growing so fast that some experts believe it overtook the United States to become the world's biggest emitter in 2007, and countries like India, Brazil and Mexico are following the same path, although not on the same scale.

These are still relatively poor countries, and so their best option for keeping the lights on, as the demand for electricity grows by leaps and bounds, is the cheap and dirty solution that everybody in Europe also chose before they got rich: coal-fired generating stations. (China is currently opening a new, large, coal-fired power plant *each week*.) These are countries that can practically taste the prosperity that only one or two more decades of high-speed industrialization will bring, and after centuries of being poor and disrespected they have no intention of stopping. Yet it will do little good for the older industrial countries to curb their greenhouse-gas emissions if the newer ones let their emissions rip. Some deal must be devised that will let the emerging countries continue to grow their economies without tipping the whole world into catastrophic climate change.

The outlines of the deal have been obvious for ten or fifteen years, but the political obstacles are huge. (So huge that no attempt was made to include the emerging economies in the emissions caps and reductions mandated under the much-abused Kyoto Accord in 1997.) To suggest that the developing economic giants accept the same curbs as the fully developed countries while there is still such a great gulf between the living standards of their citizens is simply to invite a punch in the face, so the deal has to include two key elements. First, the rich countries have to accept even deeper cuts in their emissions in order to leave the emerging economies some scope for expanding their emissions. Second, there has to be not only technology transfer, but direct financial subsidies from the developed countries on an extremely large scale, in order to give the developing countries adequate resources for the task of switching their power-generation capacity from fossil sources to (more expensive) non-fossil technologies. Governments on both sides of the fence understand the shape of the deal that must be done, but the politics of it is very hard to manage in the developed countries, while the managers of electricity grids in the fast-growing countries of Asia are in a race just to keep the lights on. They will need a lot of help if they are to make the right choices.

Negotiating such a deal—a global deal, with everybody included—will be the second-hardest political enterprise ever undertaken. The hardest will be selling the completed package to the political audiences back home. The underlying principle that would shape this deal (if it happens) and justify the vast transfer of resources is that everybody on the planet is entitled to the same basic personal allocation of greenhouse-gas emission rights, and that those who exceed that allocation must compensate for those who use less than their permitted amount. If that deal cannot be made, then we must live with the consequences. Or die from them.

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SCENARIO FOUR:
NORTHERN INDIA, 2036

> In December 2001, when terrorists attacked the Indian parliament, India blamed Pakistan and withdrew her High Commissioner in protest . . . At a seminar in Karachi in the last week of December 2001, attended by ICPI [International Center for Peace Initiatives], the only occasion when tensions rose was when someone alleged that the Indian government had plans to use the water weapon. A participant warned that any conflict over water would lead to Pakistan using nuclear weapons on a first strike basis against India.
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> —*The Final Settlement: Restructuring India-Pakistan Relations*, published by the Strategic Foresight Group, ICPI, Mumbai, 2005

The surviving monkeys still play amid the ruins of the Taj Mahal. They come out of habit, although there are no longer any tourists leaving food around. Even if there were much left worth seeing on the site, the radiation levels are still too high. There are fewer monkeys than there used to be, too, for the blast was less than five kilometres away. It was a ground burst, to crush the aircraft in their shelters, and although it happened on the first day of the war, when both sides were still avoiding strikes against cities, it happened to Agra Air Force Station, located right at the western edge of the city. Maybe the Pakistani planner who put it on the target list didn't know about the Taj, or maybe he felt that he couldn't afford to care.

Flat and low-built, the city of Agra gave the Taj Mahal little protection from the blast. The three million people who used to live in the city had even less protection, and those who survived have mostly fled south, for the whole of northern India as far east as the city of Kanpur is still fairly radioactive, even three months after the short-lived nuclear exchange ended. In the final spasm of city-killing most of the big Indian cities were hit even in the south, but here in the north, every air-force base, every army cantonment, everything of military value was targeted from the start. Foreign observers doing counts from satellites estimate that the corridor along the Grand Trunk Road from Allahabad up through Kanpur and Delhi to Amritsar, taking in most of the densely populated upper Ganges Valley and the eastern Punjab, was hit by over three hundred warheads in six days. That's still only one nuclear weapon for every five hundred square kilometres, on average, but the fallout plumes overlapped almost everywhere.

Pakistan, from the satellite and UAV (unmanned aerial vehicle) reports, is even more grievously wounded, for it had less hinterland to start with. From Peshawar through Lahore and on down to Multan, the density of nuclear strikes was higher than in northwestern India. Further south in the Indus valley there were fewer strikes, but the cities of Sukkur, Hyderabad and Karachi all took multiple hits. You would think that there would be no functioning state on either side after all this—but you would, of course, be wrong. Like cockroaches, governments are largely immune to nuclear war.

New Delhi is a series of shallow, overlapping craters, but a provisional Indian government and a military command centre are attempting to reassert central control over the country from somewhere near Nagpur. The surviving Pakistani authorities are operating from bunkers near the ruins of the city of Rawalpindi. And while the ceasefire is holding, each still insists that the war was the other side's fault. Both are probably right.

Neither side would have behaved so obstinately if it were still able to feed its people, but the increasingly frequent failure of the summer monsoon was hitting Indian agriculture very hard, and both countries had been suffering for many years from the severe summer flooding of the glacier-fed river systems that rose in the Himalayas (the Indus, Ganges and Brahmaputra) as the glaciers melted. It didn't help, of course, that they had so many people who expected to eat well: there were well over two billion people in the Indian subcontinent by 2036, and a large proportion of them aspired to consume at a fully industrialized level.

Neither Pakistan nor India could produce enough food to cope with demand, and neither could buy enough on the international grain market to fill the gap, even with their newfound wealth. The international market had shrivelled to almost nothing as global warming hit agriculture right across the planet. Still, they staggered along somehow—until the summer flooding in the glacier-fed rivers turned to summer droughts.

It was perfectly predictable, and had been widely predicted for decades: first the glaciers will melt, overfilling the rivers every summer—and then they will be gone, and the rivers will run dry in the summers. It was a gradual process, and it didn't happen on every river at the same time, but by the mid-2030s the flow on most major rivers rising in the Himalayas was sharply down. This was a medium-sized problem for India, where a very large proportion of the crops is rain-fed. But it was a life-and-death crisis for Pakistan, a country that is essentially a desert with a big river flowing through it. At least three-quarters of Pakistan's food was grown on land that was irrigated by the Indus river system. It was, indeed, the largest single area of irrigated land in the world. And, by 2036, the Indus system was running on empty.

What turned an ecological problem into an international crisis was the fact that five of the six rivers that eventually feed into the Indus system rise in Indian-controlled territory. In undivided, British-ruled India, the water flowed unhindered into the intricately linked irrigation canals that covered much of the provinces of Punjab and Sind, but Partition in 1947 left most of the headwaters in Indian hands, while well over four-fifths of the farmers who depended on the water lived in the new state of Pakistan. Moreover, several of the rivers had their headwaters in the state of Kashmir, itself a disputed territory and the scene of the first Indo-Pakistani War. Fortunately, there was more than enough water available to meet everybody's needs: the mean annual flow of the Indus system in the first half of the twentieth century was 216 billion cubic metres, and, on the eve of partition in 1947, 98.7 billion cubic metres was still emptying into the Arabian Sea unused. India briefly interrupted the flow of water from its side in April 1948 in an attempt to force a new agreement, but there was no open conflict over the division of the waters and, after a dozen years of on-off negotiations, the two countries signed the Indus Waters Treaty in 1960.

It was a rough-and-ready division of the resource, mediated by the World Bank, that gave the three eastern rivers (Sutlej, Ravi and Beas) to India, and the three western rivers (Indus, Jhelum and Chenab) to Pakistan. This gave Pakistan over four-fifths of the total flow since the western rivers were much bigger (out of 216 billion cubic metres of water in the system, the three eastern rivers contained only 40.7 billion), but many Pakistanis still felt cheated: before Partition only about a quarter of the flow in the three eastern rivers had been used for irrigation on what was now the Indian side, and now India got it all. Moreover, India got the right to take enough water from the Jhelum and Chenab rivers to irrigate some 200,000 hectares of land. But Pakistan received substantial payments from India, supplemented by a large amount of foreign aid, to build new canals to redistribute water more efficiently among the western rivers, so everybody lived happily ever after—for a while.

But populations grew, especially on the Pakistani side, where the 34 million people of 1951 had multiplied to 170 million by 2008. By then, *all* the water in the Indus system was being used: in some months of the year the river did not reach the sea at all, and sea water was penetrating up to eighty kilometres into the estuary, causing increased salination in almost half a million hectares of farmland. The per capita availability of water to Pakistan's population had fallen from 5,300 cubic metres a year at Partition to only 1,000 cubic metres annually by 2008, a level that the United Nations defines as "critical," but at that point Pakistan could still feed itself.

Over the next three decades, Pakistan underwent a remarkably steep fall in its birth rate, reaching replacement level by the early 2030s. However, the very young age structure of the population, a legacy from the high birth rates of previous generations, meant that Pakistan's population still reached 290 million by 2036. If the country had continued to receive as much water as it did in the first decade of the twenty-first century, per capita availability of water would nevertheless have fallen to only about six hundred cubic metres a year—but, by the century's fourth decade, Pakistan was getting far less water from its rivers than before. The glaciers had almost all melted away, the water that used to fall as snow in the winter to replenish those glaciers now fell as rain and ran off immediately, and in the summers the rivers were only a shadow of their former selves.

Successive Pakistani governments did all the right things to alleviate the problem: barrages and dams were built to retain winter runoff for the summer, the irrigation canals were lined to reduce water loss through seepage, and drip irrigation systems were widely installed for the final delivery of the water. But nothing could really compensate for the fact that there was much less water in the rivers, and the worst hit was the Indus River itself. The Indus alone accounted for more than half the total flow of all six rivers in the system, but it was

90 percent glacier fed, and as the massive glacier on Mount Kailash in western Tibet melted away, its flow first soared and then plummeted. By 2036, Pakistan's three rivers, the Indus, Jhelum and Chenab, were delivering much less than half of their historic supply of water. In terms of water per person, Pakistan was only receiving 250 cubic metres a year: one-quarter of the United Nations' "critical" level.

India was also suffering severe problems with food supply by 2036. With the global temperature rise cutting into its existing productive capacity, it had only managed to expand domestic food production by 20 percent in the previous three decades, despite investing huge amounts in agriculture. Meanwhile, its population had grown from 1.1 billion to 1.5 billion. But India's plight was much less grave than Pakistan's, since only a small proportion of its agriculture depended on glacier-fed irrigation systems. Even in the eastern (Indian) Punjab, where grain production depended heavily on water from India's share of the Indus system, the three "Indian" rivers, the Sutlej, Ravi and Beas, relied much less on glacial melt for their flow and still delivered almost as much water as before. That, however, was precisely the fact that annoyed the Pakistanis so much.

"Annoyed" is too weak a word, really. The Pakistanis had always felt that the crude division of the waters embodied in the Indus Water Treaty had been skewed unfairly to India's advantage, given that India was using very little water for irrigation, even from the eastern rivers, at the time when the British Raj was originally divided between the two successor states in 1947. There was a chronic, and sometimes accurate, Pakistani complaint that the great powers tended to favour India when they mediated between the two countries because India, so much bigger and richer, was more important to their own long-range plans. Now, on top of that, came the bitter realization that the western rivers were failing Pakistan, while the eastern rivers still gave water to India.

There had been no overt military confrontation between the two countries since the Second Kargil Crisis of 2017, and even that had not gone beyond infantry and artillery clashes in Kashmir. The knowledge that the other side also possesses nuclear weapons instills a large degree of caution in even the most irreconcilable opponents. But almost ninety years after Partition, the mutual hostility between the two countries had not really faded, and the political temptation to scapegoat the wicked neighbour was ever-present. Pakistan had been in one of its interludes of civilian rule since 2018, but the helplessness of the elected governments in the face of the rapidly growing crisis of water supply (and therefore of food supply) steadily undermined their credibility.

In June 2035, the sixth military coup in the country's history brought a "Council of National Salvation" (CNS) to power. It differed from the previous five coups in two important respects. One was that it was carried out by relatively junior officers, mostly colonels, without the consent of their legal superiors: for the first time, the armed forces were not intervening as a disciplined whole. The other, closely connected to the first, was that it was not the usual bloodless affair. Generals were rounded up and, in a number of cases, when loyal troops tried to protect them, there were firefights in the streets. Some generals were subsequently executed, as were some politicians from previous governments whom the colonels felt had betrayed the national interest. It was early July before the CNS was fully in control of the country, and by then Pakistan was polarized as never before. The young colonels probably had majority support among an increasingly desperate population, but they certainly felt the need to solidify that support through prompt and dramatic action on the key questions of water and food.

In late July, they publicly demanded that India stop taking its small, treaty-mandated share of the water from the upper reaches of the Jhelum and Chenab rivers, and more importantly, that it give half the water from the eastern rivers to Pakistan. (Even if India were to grant their demands, it would only have solved about a third of Pakistan's water problem, but the young officers had no ideas about how to address the rest of it.) They also secretly instructed the directorate for Inter-Services Intelligence to send guerrillas into the Indian-controlled part of Kashmir, as it had done during a number of previous crises—but this time they had orders to attack the headworks on the rivers that flowed through the disputed province in order to raise the pressure on New Delhi.

The Indian government had been watching the growing desperation of Pakistan's leaders with concern for years, well aware that it could have grave implications for India, and the Ministry of External Affairs and the Indian armed forces had both gamed possible crises arising from it (though never together, of course). But neither India's generals nor its diplomats had foreseen such a radical and unpredictable regime coming to power in Islamabad and, over the ensuing months, there was much inconclusive debate in South Block about how to deal with it.

The guerrilla raid on the giant Bhakra Dam on the Sutlej River in March 2036 put the turbines in the north powerhouse out of operation for several months, but its main effect was to trigger the collapse of the coalition government in New Delhi. The new coalition that took its place in April included two hardline nationalist parties, and was pledged to put an end to the "terrorist" threat at any cost. The simplest way to do that, it reasoned, was to put unbearable pressure on the Pakistani sponsors of the attackers, and so it mobilized the Indian armed forces and moved a number of armoured formations up to the border with Pakistan.

There was no intention actually to attack Pakistan, of course, but the planners in New Delhi reckoned that the deployment of Indian armour near the frontier would force Islamabad to flood the very extensive network of "defence canals" that it had built at strategic locations along the border to prevent crossings by Indian armour and artillery, in the event of war. The water diverted to these canals would greatly exacerbate the existing water shortage in Pakistan and would put the Islamabad regime under great pressure to back down from the confrontation.

That was the plan, but while the young colonels in Islamabad did flood the defence canals as predicted, their political position at home was too precarious to let them back down gracefully. Foreign exchange to buy scarce and very expensive food on what was left of the international grain market had run out, food rationing had already been imposed in Pakistan's major cities, and they desperately needed a victory—so they issued an explicit threat to use nuclear weapons if India did not withdraw its troops from the border.

This was a potentially suicidal threat, since India had at least as many nuclear weapons as Pakistan and much better protected delivery systems. But the Council for National Salvation was operating on the familiar fallacy that the other side, in addition to being in the wrong, is morally inferior and will lose its nerve if pressed hard enough. What the Indians actually did was to start planning a non-nuclear pre-emptive strike to destroy Pakistan's nuclear delivery systems on the ground, using swarms of the small (thirty to fifty kilograms), heavily stealthed, highly accurate unmanned aerial vehicles that India had acquired as a result of its close defence relationship with the United States. A few Pakistani nuclear weapons would doubtless escape, but Indian air defences and anti-ballistic missile defences would deal with most of them and, at worst, India would take a couple of nuclear hits. Waiting for the "crazy colonels" to carry out their threat, it was argued, would lead to an infinitely worse outcome.

It should have set off alarm bells in New Delhi when the U.S. government started withdrawing all military and diplomatic personnel from India and urgently advising all American citizens to leave, but the Indian plan was set into motion at 3 a.m. local time on May 25, 2036. Well over half of Pakistan's nuclear weapons were destroyed before dawn on that day, by thousands of Indian UAVs homing in on their locations with relatively small packets of high explosives. As the crisis deepened, however, many of Pakistan's nuclear weapons had been redeployed from their usual locations, and Indian satellites had not picked up on all of the new locations. As soon as the Indian UAV strike got underway, the Pakistani colonels ordered instant nuclear strikes on all the bases in India that were believed to harbour nuclear weapons. In principle, the Pakistanis were still trying to avoid cities at this point, but their target list included places like Agra Air Force Station (long runways, big aircraft capable of launching lots of cruise missiles) and Bombay Dockyard (ships and submarines with cruise missiles), only a couple of kilometres from the city's heart.

By Day Three, even these crude distinctions among targets had been lost, and the remaining nuclear weapons (not many, by now) were mostly just aimed at population centres. The logic of this kind of conflict is inexorable: you cannot "win" a nuclear war, but if you want the survivors on your own side to have any future, you will try to ensure that they are not outnumbered by the survivors on the other side in the places that are important for their future. Besides, there really was no command and control left at this point: whoever still had a weapon, fired it at whatever target they had coordinates for—and everybody with a computer or even an atlas had coordinates for the cities.

On the sixth day, the nuclear war sort of petered out for lack of long-range weapons, and the de facto ceasefire became a formal arrangement a few days later, when provisional governments began to assert their authority over what was left of the two countries. Fatal casualties in India and Pakistan, including radiation victims who died in the first month after the war, were on the order of four to five hundred million, though exact figures will never be known. The Himalayan mountain wall protected China from most immediate fallout, but the prevailing winds delivered large doses of it across Bangladesh, Burma and northern Thailand, where some millions died as a result. There were not nearly enough weapons detonated to cause a "nuclear winter," but sufficient dust was boosted into the atmosphere to cause a cooling of about one degree Celsius in the Northern Hemisphere during the summer of 2036.

By the winter of 2036–37, columns of armoured vehicles, modified to provide some protection against radiation, were making their way back into the devastated zones on both sides of the old frontier. To avoid the hot spots, they used radiation maps plotted by UAVs. The aim was not so much to bring help to survivors who had not managed to flee—there were not enough resources for that—as to reassert control over the national territory. India had to divert a great deal of its effort to the northeast, however, as neo-Naxalite groups had taken advantage of the chaos to seize control of much of Orissa, Jharkand and Bihar states, and the suspension of armed patrols along the border fence had allowed millions of Bangladeshi economic refugees to pour into the states of Assam and Tripura. That distraction, plus the relatively greater distance to be traversed by Indian columns, allowed Pakistani forces to gain control of the state of Jammu and Kashmir, together with the headwaters of all but one of the rivers of the Indus system. So it was a Pakistani victory, in the end, albeit one that would have shocked even Pyrrhus.

CHAPTER SIX
Real World Politics: The Copenhagen Conference

Watching this stupid summit by webcam (I wasn't allowed in either), it struck me that the treaty-making system has scarcely changed in 130 years. There's a wider range of faces, fewer handlebar moustaches, frock coats or pickelhaubes, but otherwise, when the world's governments tried to decide how to carve up the atmosphere, they might have been attending the conference of Berlin in 1884.

It was as if democratization and the flowering of civil society, advocacy and self-determination had never happened. Governments, whether elected or not, without reference to their own citizens let alone those of other nations, asserted their right to draw lines across the global commons and decide who gets what. This was a scramble for the atmosphere comparable in style and intent to the scramble for Africa . . .

Most rich and rapidly developing countries [the U.S., the EU, Japan, China, India, etc.] sought in these talks to seize as great a chunk of the atmosphere for themselves as they could—to grab bigger rights to pollute than their competitors. The process couldn't have been better designed to produce the wrong results.

—*Guardian* report by George Monbiot,
December 18, 2009

> It's not democratic, it's not inclusive. Well, ladies and gentlemen, isn't that the reality of the world?
>
> —Hugo Chavez, president of Venezuela, in a speech at the Copenhagen Conference, December 18, 2009

Even stopped clocks are right twice a day. Hugo Chavez may not match that performance, but he *is* right sometimes, and this was one of the times. The Copenhagen Conference of December 2009 was a replay of the Berlin Conference of 1884, more or less—except that it didn't end the same way. The division of Africa agreed at Berlin kept the European great powers out of war with one another for the next three decades. There was no real agreement at Copenhagen.

The business of moving from fossil fuels to other sources of energy is relatively straightforward. The alternative technologies exist, and implementing them over twenty or thirty years would probably cost no more than 1 or 2 percent of a nation's GDP. The obstacles that keep this from happening are all political: at the national level, the influence of special interests and just sheer disbelief; at the international level, an obsessive concern with fairness (at best) or with comparative advantage and narrow national interests (at worst).

If there were a world government, of course, it would simply identify the danger, pass the necessary laws, and get on with eliminating fossil fuels, but for various reasons, both good and bad, no world government exists. We must address this danger with the very complex and cumbersome international system we have, where almost two hundred countries must first achieve some national consensus on policy, and then build a global consensus for action on that shaky foundation.

It's the old story of the lost traveller in Ireland, asking the way to his destination from a local. "If that's where you want to get to, sir," the Irishman replies, "I wouldn't start from here." It would be much better not to start from here, but we have no choice in the matter, so we need to understand what grand and petty considerations of a political order get in the way of our doing what we obviously should be doing. For that, the climate summit at Copenhagen in December 2009 is a very good place to start.

When we examine the strategy and tactics of various players at and before the Copenhagen Conference, there will be much to criticize, but it is important to remember that almost everybody there was genuinely concerned about global warming, and wanted to achieve an agreement that addressed the problem seriously. We should also bear in mind how the pre-Copenhagen dispensation on climate change, with its very unequal requirements for cutting greenhouse-gas emissions, was originally arrived at.

By 2009, most European countries had reduced their emissions enough to meet or exceed the targets they had agreed to in the Kyoto Protocol of 1997, the first international treaty that tried to curb global emissions. The average cut that the Protocol set for the long-industrialized countries was just 5 percent below their 1990 emissions, but achieving even that modest reduction in emissions by 2012, the diplomats at Kyoto had believed, would put the world on the road to a solution. Back in 1997, the steady rise in the emissions of the developed countries was still seen as the core of the problem. Turning that rise into a decline would begin to solve the problem, although it was possible that a follow-on climate accord after 2012 might need to set a more ambitious target for reductions.

European compliance with Kyoto in the following years was good, although a few countries, like Spain and Italy, missed their targets by a wide margin. The relatively impressive European performance, however, was partly due to the rapid collapse of highly polluting Soviet-style heavy industry in Eastern Europe after 1990. It also owed something to the globalization process, which saw the developed countries export much of their industrial production, together with the resulting carbon dioxide emissions, to China and other Asian producers in the two decades after 1990. Nevertheless, Europe did keep its overall commitments.

Elsewhere, the record was bleaker. Neither Japan nor any of the larger English-speaking countries outside Europe came anywhere near their targets. Canada, the rogue state among the developed countries, promised to cut its emissions by 6 percent at Kyoto in 1997 and actually ended up 29 percent above that target by 2006. The United States never ratified the Kyoto treaty (and officially "unsigned" it as soon as George W. Bush became president in 2001), but it still did somewhat better than Canada, its emissions increasing by only 17 percent in the decade after 1997. But these local failures could be rectified as soon as the local governments changed—and indeed, by 2009 they had already been replaced by more climate-friendly governments in Australia, Japan and the United States. The key problem with the Kyoto treaty turned out to be not the behaviour of the rich countries, but the distinction that it made between the rich countries and the poor ones.

The argument of the developing countries at Kyoto was that they were not responsible for global warming, since their greenhouse-gas emissions were very low. Yet they were going to be the principal victims of it, or at least the earliest ones. More than 80 percent of all the excess carbon dioxide in the atmosphere attributable to human activities came from the developed countries, some of which had been spewing the stuff out for two centuries. So it was the duty of the developed countries to solve the problem by cutting their emissions, while the poor countries should not be subjected to any limitations on their relatively tiny emissions as they struggled to grow their economies.

The argument for historical justice carried the day at Kyoto, and the developed countries became the "Annex 1" countries that bore the full responsibility for dealing with global warming. The industrialized nations only agreed to this, however, because the actual emissions cuts they were being asked to make were relatively small—and because in 1997 nobody thought that the uncontrolled emissions of "Annex 2" countries like China, India and Brazil would become a major factor in the global heat balance. Those developing countries were still poor, with very low per capita emissions, and the conventional wisdom expected them to stay that way.

Wrong. What seemed like a flash in the pan in 1997 turned into a decade of sustained high-speed economic growth in developing countries that contained half the population of the planet. The emissions of the Annex 2 group soared, and as a result, the anthropogenic carbon dioxide entering the atmosphere, instead of declining gently at the rate of about half a percent a year, grew by 2.5 to 3 percent annually. The world has turned out to be a very different place than the negotiators at the Kyoto Conference expected, and economic growth in the developing world will account for 90 percent of all the future growth in human carbon dioxide emissions worldwide. Yet these same developing countries got a legally binding exemption from having to curb their emissions in the Kyoto treaty, and they have subsequently been most reluctant to give it up. They see hard targets for controlling their emissions as incompatible with their first priority of growing their economies.

This was not the only flaw in the Kyoto accord. The so-called Clean Development Mechanism was a well-meant attempt to encourage rich countries to invest in schemes to cut emissions in developing countries, by giving the developed nations credits that they could apply against their own carbon reduction commitments. If Germany didn't want to shut down its coal-fired power stations, say, it could achieve the same emissions reductions (at least in legal theory) by subsidizing a project to curb deforestation in Indonesia or Brazil. In practice, unfortunately, accounting for the emissions "saved" in developing countries proved to be nightmarishly difficult, and many of the players ended up quite cynically gaming the system. Much money was made; few emissions were avoided.

Worst of all, the whole methodology of the Kyoto process, while it made sense in terms of human politics, made no sense at all in terms of natural systems. Haggling over percentage cuts in the greenhouse-gas emissions of various countries is a familiar procedure for which we have many precedents, but it has no connection to the objective scientific evidence about how big and how fast the cuts need to be.

A more rigorous process would start by measuring how much more anthropogenic carbon dioxide can be released into the atmosphere between now and 2050, say, or by some other relevant date, without pushing us all past the boundary of plus-two degrees Celsius and into runaway warming. *Then* the negotiations would begin with an acknowledgement by all the participants of exactly how big and how fast the global cuts in emissions needed to be. There would still be much haggling about how the pain of these cuts was to be shared, and the talks would be complicated by the awkward fact that the developed countries were responsible for most past emissions while the developing countries will be responsible for most future growth in emissions. But at least the targets would be grounded in the physical realities of climate change.

To be fair to the Kyoto negotiators of 1997, climate scientists at that time were not yet able to come up with hard numbers for the global emissions cuts needed to avoid eventual climate disaster. The negotiators were also attempting to do something that had never been tried before: to control the emissions, and by implication some of the fundamental economic choices, of an entire global civilization. They got a lot of the details wrong, but they did succeed in establishing the principle of the "common but differentiated responsibility" of all countries for the health of the atmosphere, and indeed, of the biosphere. No country has the right to disregard the effect of its emissions on other countries (although in practice, of course, some did). Kyoto was not a wasted effort, and its lack of ambition was largely due to ignorance about the true scale and speed of the emissions problem.

The science has advanced rapidly in the intervening years, however, and we now have much better numbers. They are quite daunting.

In the April 2009 edition of the leading scientific journal *Nature*, two teams of scientists published loose but convincing estimates of how much more greenhouse gas human beings can afford to emit. The team led by Malte Meinshausen of the Potsdam Institute for Climate Impact Research worked to the time horizon of 2050, and calculated that total human emissions between 2000 and 2050 should not exceed one trillion tonnes of carbon dioxide equivalent (the sum of all greenhouse-gas emissions expressed in terms of CO_2 alone) if we want to limit the risk of exceeding two degrees Celsius of warming to only 25 percent. Since anthropogenic greenhouse gases in the atmosphere are currently growing by about two billion tonnes a month, that allowance could actually run out even before 2030.

The other team, led by Myles Allen, head of the Climate Dynamics Group at Oxford University's Atmospheric, Oceanic and Planetary Physics Department, took a longer view and tried to calculate how much room we had for emissions between now and the year 2500. The answer was that human civilization can afford to produce only between sixty-three and seventy-five years of greenhouse-gas emissions at the current rate over the next five hundred years if we wish to minimize the risk of runaway warming. All the scientific evidence pointed to the need for a much more ambitious treaty than the Kyoto accord, which was anyway going to expire in 2012.

The decision to hold a major conference in Copenhagen in late 2009 to craft a follow-on treaty to the Kyoto Protocol was taken by the signatories at a meeting in Bali in 2007. Though they did not yet have Meinshausen's and Allen's figures, they were already well aware that the scale of the problem was far bigger than the original Kyoto negotiators had understood. Not only had those pioneers failed to foresee the rapidly rising emissions of the developing countries, which totally overwhelmed the modest cuts made by some of the developed countries, but they had not understood the risks of runaway warming that would begin to operate at around plus-two degrees Celsius.

This time around, there was much more realism about what needed to be done than there had been at Kyoto. The Association of Small Island States (AOSIS), for example, went to Copenhagen advocating the 350 parts per million target proposed by James Hansen, on the grounds that many of those low-lying island countries would be overwhelmed by the rising sea level if the Conference accepted the 450 parts per million/+2 degrees Celsius target espoused by most other countries. Most of the African countries had figured out that their continent was going to be struck first and worst by the warming, and some were beginning to question (in private) the policy of the Group of 77 (G77) developing countries, which defended the blanket exemption from emissions targets that those countries had achieved at Kyoto. Everybody understood that there had to be some serious money on the table to compensate the developing countries for the climate changes they were going to suffer through no fault of their own, and to bridge the price gap between the cheap fossil fuels that they would naturally turn to as their economies grew, and the more expensive renewable sources that they should be building instead.

Everybody also understood that no final treaty would be complete and ready for signature at the end of the Copenhagen Conference, which was scheduled for two weeks in December 2009. A final treaty had certainly been the original intention, but several hundred pairs of square brackets (denoting points not yet agreed) remained in the draft treaty as the Conference opened. Turning those square brackets, each containing two, three or many rival proposals, into definitive text was far too large a task to be completed in two weeks, even if all the rival interests they represented had been instantly reconciled.

The most that might be accomplished in the time available was that the 192 countries present would work through most of the minor points of disagreement in the two weeks available. To resolve the major disputes, they hoped for a high-level deal among the leaders of the biggest emitting countries, most of whom were scheduled to turn up for the closing days of the Conference. Then, the Conference could close with a ringing declaration of intent supported by everyone, lower-level talks would fill in the remaining blanks in the draft treaty as fast as possible, and a final treaty would be ready for signature some time in 2010.

When the Conference opened on December 7, most of the thousands of arriving delegates were still optimistic that something meaningful might be achieved. Three great stumbling blocks remained, however: the United States, China, and the exemption of even the richest, high-emitting developing countries from any obligation to curb their emissions. Of those three, the most important was probably the inability of the new U.S. president to offer any reliable American commitment to cut emissions.

> [Obama] is not going to say by 2020 I'm going to reduce emissions by 30 percent. He'll have a revolution on his hands. He has to do it step by step.
>
> —Rajendra K. Pachauri, head of the Intergovernmental Panel on Climate Change, March 11, 2009

Barack Obama clearly understands the importance of avoiding disastrous climate change, but few of the Americans who voted for him had that as their highest priority. Their primary concerns were jobs and health care, so Obama had to put these issues first. The first bill he brought to Congress was a measure to rescue the U.S. economy from recession by throwing large sums of money at the problem, and the second was a reform bill to extend health coverage to the tens of millions of Americans who had none. A climate-change bill pledging modest cuts in U.S. emissions only came third, although he initially hoped to be able to go to Copenhagen with that commitment in hand. By the autumn of 2009, it was clear that even the health bill would not be finished before the end of the year, and that Obama would therefore be going to Copenhagen empty-handed. In October he began talking about the Copenhagen Conference as a "staging post," not a destination.

Even if Congress had moved faster, Obama's offer at Copenhagen would have been very modest indeed. Most other industrialized countries were talking about 20 or 30 percent cuts in emissions compared to the 1990 baseline—in the case of the new Japanese government, even a 40 percent cut. Obama's bill talked about 17 percent U.S. cuts, *but only compared to 2005 U.S. emissions*. By moving the goalposts from 1990 to 2005, he sought to give the impression that he was making a meaningful offer, but compared to the 1990 standard used by everybody else it was a paltry 4 percent cut. The United States—or at least the Washington political world—simply wasn't ready for anything more ambitious.

Since key players like China understood that Obama would do more to curb U.S. emissions as soon as it became politically possible, there might still have been a real agreement at Copenhagen if he had shown up with that modest commitment approved by Congress. After all, it would have been the first time that the United States committed to any curbs whatsoever on its emissions, and that principle is more important than any specific number attached to it. But the principle was not secure, because the bill had not yet made it through Congress. Indeed, it was uncertain that it ever would be passed in a recognizable form.

Effectively, there are two governments in the United States: the executive branch (the White House) and the legislative branch (the Congress). Obama leads only one of them, so he really did have nothing to offer other than a statement of intent, and that wasn't enough. That is probably why Obama originally planned to drop into Copenhagen for a day at the beginning of the Conference on his way to collect his Nobel Peace Prize in Oslo, but to skip the closing days when most other heads of government would be present in the Danish capital.

The problem with China seemed to be of quite a different nature, but in the end it turned out to be very much the same. The apparent problem was that China is still an Annex 2 country, exempt from any obligation to cut its emissions, although it has also become the biggest emitter in the world. (China overtook the United States in emissions in 2007.) While large parts of China are still poor, the per capita carbon dioxide emissions in thirteen Chinese provinces are higher than per capita emissions in France. China's ultra-rapid economic growth depends on an equally rapid expansion of the power supply, and that can only be achieved without crippling expense by exploiting the country's abundant reserves of coal.

It's not that the Chinese government ignores the problem of global warming. On the contrary, it is well aware that China is extremely vulnerable to climate change. It is a country of about the same size as the United States, located in about the same latitudes, but it has four times as many people, much less agricultural land, and some specific vulnerabilities like its heavy dependence on glacier-fed rivers (in the south) and on the northeast monsoon. So China is making a huge investment in wind and solar power, aiming for 15 percent renewables in its energy mix by 2020. It has one of the world's highest requirements for fuel efficiency in vehicles—45 mpg—in order to diminish the environmental impact of the new cars that are flooding the roads (China is now the world's largest automobile manufacturer). But in the end, it depends on coal to keep the lights on—69 percent of its primary energy comes from coal, almost twice as high as the global average—and it will continue to rely heavily on coal for several decades.

This dependency on coal is decisive in shaping Chinese policy on any international treaty covering emissions. It does not want to be forced to accept targets that will constrain its economic growth at a time when a majority of Chinese are still poor, so it has taken a leadership role in the resistance by the G77 to any attack on their exemption from emissions cuts under Kyoto. Its other main consideration, going into Copenhagen, was that it would *never* accept any restrictions on its emissions until the United States did so—and the United States had yet to accept any at all.

On the other hand, China was concerned about the possibility that it would become isolated diplomatically on the climate issue, with potential spillover into other areas like trade that are also of great importance to it. Isolation was a real concern, for many of the developing countries that had been China's allies in Kyoto, but that did not have rapidly industrializing economies, were beginning to rethink their priorities. What is the point in being exempt from emissions cuts if your emissions aren't growing that much anyway? And what damage will be done to your country by collapsing agriculture and rising sea levels if global emissions are unrestrained? The risk of a split in the G77 was not visible before Copenhagen, but it was already present.

So in the weeks leading up to the Copenhagen Conference, China announced a target not for cuts in carbon dioxide emissions, but in "carbon intensity"; that is, in the amount of carbon dioxide that is emitted per unit of economic activity. Beijing said that it would make 40 to 45 percent cuts in carbon intensity by 2020, compared to 2005 levels. India followed with a declaration that it would cut carbon intensity by 24 percent by 2020. These were not legally binding commitments, and in neither case would their emissions actually stop growing. But they would at least grow more slowly relative to the growth of the entire economy—in China's case, only about half as fast. As the first-ever statements showing a willingness to control emissions growth from the two biggest industrializing countries, the Chinese and Indian declarations were warmly welcomed.

The third stumbling block that hampered the negotiators at Copenhagen was the question of whether they were renegotiating the Kyoto accord or forging an entirely new treaty. Technically, there was no doubt about it: those who arranged the Conference in the first place were all part of the Kyoto process, and had no intention of abandoning it. However, a number of Western countries, including the United States, the United Kingdom and the host of the Conference, Denmark, calling themselves the "circle of commitment," were secretly working on a draft proposal that would replace the whole Kyoto process with a new treaty that obliged developing countries to make emissions cuts in return for financial aid. This draft also envisaged that even in 2050, the permitted emissions per person should be almost twice as high in developed countries as in developing ones.

The "Danish text" was not so much an evil document as an astoundingly stupid one. For example, rich countries with a long history of high emissions *should* be giving developing countries financial aid that is specifically earmarked to help them cut their emissions, whether from industry, agriculture or forestry, but that aid should be kept quite separate from money to help poor countries adapt to the warming that is already impossible to prevent. The latter should come without strings, since the warming is a burden that the developed world has imposed upon the developing—and neither of these forms of aid should be confused with the traditional foreign aid that is given to help poor countries develop their economies. The Danish text in effect sought to put all three types of aid together, and turn them into a lever by which the rich countries could force the poor ones to reduce their emissions.

To imagine that such a change could be successfully foisted on the poor countries at Copenhagen was simply breathtaking in its ignorance and arrogance. Equally detached from reality were the proposals in the Danish text to establish a two-tier world of different emissions rights for rich and poor countries, in effect institutionalizing current inequalities, and to give control over the choice of who gets climate-related aid to the deeply unloved, Western-run World Bank. The document was presumably intended to be sprung on the Conference near the end, when all the world leaders were present and the negotiations had reached deadlock, but it was (of course) leaked before the Conference even began, and caused huge anger among the intended victims.

That was one of the reasons why the Conference was confrontational and shambolic from the first day. Another was that there were far too many people involved—about five thousand accredited delegates—to permit the kind of concentrated work on details that was needed to eliminate all of those square brackets. And the killer was that the Conference would have run more smoothly if it had been organized not by the Danish government but by a troop of baboons.

Delegates arriving directly from the tropics, with no warm clothing, queued for hours outside the Bella Centre without food or drink in the depths of a Danish winter as they waited for accreditation. A number were taken to hospital suffering from exposure. China's chief negotiator was barred by security for the first three days of the meeting, a matter that should have been sorted in three minutes, leaving the Chinese delegation in high dudgeon. And the atmosphere was soured from the start because just two months before the Conference opened, the Danish prime minister, Lars Løkke Rasmussen, fired the deputy permanent secretary at the Ministry for Climate and Energy, Thomas Becker, who had been the driving force in bringing the Conference to Copenhagen in the first place. As chief negotiator during two years of preparatory meetings, Becker had fostered a sense of trust in the process among the developing countries, and his dismissal was greeted with alarm. Probably rightly so, as it was part of a broader struggle between the prime minister's office and that of Climate Minister Connie Hedegaard, possibly over the then-still-secret Danish text that Rasmussen was holding in reserve on behalf of the "circle of commitment." (In the chaotic final two days of the Conference, Rasmussen pushed Hedegaard aside as chair and took over that role himself.)

By the time the Conference began, the G77 was so suspicious of the motives and tactics of the developed countries that proceedings were repeatedly interrupted for hours or even entire days by walk-outs and boycotts. In the early days of the Conference, numerous groups of protesters roamed the Bella Centre; as security tightened towards the end they were more likely to be found outside under a rain of police clubs. The only noteworthy sign of progress in all that time was a declaration by the developed countries that they would provide $30 billion a year from 2010 to 2012 to help developing nations mitigate their emissions and adapt to climate change. By the end of this decade, moreover, that fund would grow to $100 billion annually. There were few details about how this would be accomplished, but there were no visible strings either.

As the end of the Conference neared and the presidents and prime ministers began to arrive in Copenhagen (including President Obama, who had been persuaded to return for the final day), there was still no text even remotely ready to be signed. Yet it is an iron rule of politics that very senior politicians must not be seen to fail. A ringing declaration of principles and purposes must be made that disguises the Conference's failure and lets everybody claim success, or else the failure must be convincingly blamed on the other side. Or ideally, both: the more ignorant media will believe your claims of success, and the cleverer ones will lay the blame for failure where you want it laid.

> It was extraordinary. This is important for the record. Other parties do not have the interest and awareness in climate change that we have.
>
> —José Manuel Barroso, president of the European Commission

What actually happened on the last day of the Conference was that the big emitters who had not undertaken any commitments to reduce their emissions under the Kyoto accord, the United States on one side and China supported by India, Brazil and South Africa on the other (the BASIC group), took over and produced a document more to their liking. Since they collectively account for more than 40 percent of global emissions now, and will account for an even greater share in the future, they could not be overridden or ignored. So the lesser industrial powers and the smaller, poorer developing countries that had been beavering away loyally for the previous two years to produce a serious climate treaty with hard targets and binding commitments were simply shoved aside by this transient coalition of countries that didn't want that kind of outcome.

It was not a coalition of the ignorant: the governments of all of these countries are well aware that global warming will cost them dearly, and they really do want to avoid the nightmare of a two-degrees-warmer world. They just have various domestic circumstances that make them averse to hard targets and legal commitments: congressional gridlock in the United States, and a genuine fear among the BASIC group that setting emissions targets would give their commercial competitors in the older industrial countries a lever with which to slow their economic growth. It's a pity that these local and presumably transitory concerns should take priority in decisions that potentially involve the future of civilization, but that is the way that human politics often works. The Obama administration was particularly conscious of the fact that this didn't look very good from the outside, and so a subsidiary theme on the last day was a struggle between the United States and China to fix the main blame for failure on the obstructionism of the other party.

Obama opened with a speech that indirectly criticized the Chinese for their obstructionism. The Chinese trumped that with a show of injured innocence and hurt feelings that involved Premier Wen Jiabao refusing to go to the closed-door meeting attended by the other key heads of government for the rest of the day. Instead, the other presidents, chancellors and prime ministers were obliged to deal only with mid-level Chinese officials, and wait repeatedly while those officials checked with Wen for an answer. The answer was almost always no.

As several people who were at that meeting observed, it would have been easy to come up with the ringing declaration of principles that the occasion required if the Chinese officials had not been in the room. But they were in the room, and they held the whip hand, because there was really no point in everybody else making commitments and cuts if the Chinese did not finally accept some responsibility for the problem. In particular, Obama would have no chance of getting his own modest emissions cuts approved by Congress if he could not show that China was going to be a partner in the process. So the Chinese got most of what they wanted.

The three-page agreement that emerged from the closed-door meeting on Friday night confirmed that the Kyoto treaty would remain the point of departure for any future agreement: the Western attempt to move to an entirely new treaty and end the total exemption from emissions targets for the Annex 2 countries was decisively rejected. That implied that the two years of work on a successor to the Kyoto treaty would not just be cast aside, but there was not a word about when the work would resume, let alone a deadline for completing it. The document "recognized" the scientific view that the increase in global temperature should be below two degrees Celsius, but it didn't say that this must be the guide for policy, or set any specific cuts or targets. It said that global emissions should peak "as soon as possible," but it didn't say when that should be.

It did confirm the short-term funding of $30 billion annually from 2010 to 2012 to help developing countries reduce their emissions and cope with the impacts of warming, and it repeated the "goal" of $100 billion a year by 2020, but the details of where this money might come from were absent. Above all, there were no targets at all, current or long-term, for rich countries or for developing ones. None.

Even the targets for 2050 that had been in every previous draft of the treaty, and have become so familiar that they are an almost unnoticed part of the global landscape, were stripped out of the final text at the insistence of the Chinese. The world is no longer formally committed to 50 percent cuts in carbon dioxide emissions by 2050, nor are developed countries any longer committed to 80 percent emissions cuts by the same date. The only plausible explanation is that the Chinese expect to be a developed country by then, and do not wish to be encumbered by such an onerous engagement.

Far more important than declaratory targets for 2050 were hard targets for emissions cuts by developed countries between now and 2020. Cuts in the current decade are much more important than cuts in the twenties or thirties, because carbon dioxide accumulates in the atmosphere: once emitted, it stays there for centuries. (Cuts in the decade just past would have been even more valuable, but it's too late for that now.)

However, in the final frantic negotiations on December 18, 2009, to put together the three-pager that would substitute for a real treaty and save the face of all the leaders present at Copenhagen, it became clear that China would not countenance targets even for the industrialized states. The developed countries had put their own emission reduction targets into the draft declaration (the "Copenhagen accord"), but China wanted them out. Astonishment was followed by consternation, and then by reluctant acceptance: what China wanted, China got.

"Ridiculous," scoffed German Chancellor Angela Merkel, but the percentage targets for the European Union and the other developed countries, already publicly announced by those governments, were deleted from the final document. As a European diplomat said afterwards: "China doesn't like numbers."

The Chinese stonewalling on the last day allowed the United States to portray China as the villain of the piece, but why did the Chinese delegation adopt such a hard-line position? Was Beijing not concerned about the long-term implications of global warming for food production in China, and therefore for the survival of the regime itself? How could the Americans, who were convinced that Beijing really wanted to make a deal that avoided the two-degree threshold, have gotten it so wrong?

> One of the questions that is often asked is: What are you going to do about China and India? They're only interested in development. They're not going to buy into this. Their emissions are going to keep growing . . . I don't believe that for a minute. I spend a lot of time in both China and India. I run research projects in collaboration with government organizations, think tanks, universities in China and India on climate change and what to do about it. And what I can tell you is that the Chinese and the Indians are not less knowledgeable and not less worried about this problem than we are in the United States or Canada or Europe. They are waiting for us to lead, in part because we in the industrialized world caused most of it up until now. But they understand that climate change is already harming them.
>
> The Chinese have figured out that the East Asian monsoon has been changing for thirty years in a manner predicted by the climate models . . . and that has caused increased flooding in the south of China and increased drought in the north. Chinese climate models show this. Chinese leaders know it. You go and sit privately with the

> political leaders of China and they will quote to you the results of their own Chinese climate scientists' studies showing that China is being seriously harmed today by climate change. It's the Chinese themselves who figured out that the great glaciers that feed their rivers are disappearing at the rate of 7 percent per year. That's a halving time of a decade . . . The Chinese and the Indians in my view are going to sign on to a global approach to reducing greenhouse-gas emissions within three to five years of the United States making the transition from laggard to leader. They're waiting for us to do it, but they're going to join.

Dr. John Holdren, the director of the Woods Hole Research Center, had not yet become the chief scientific adviser to President Obama when he made those remarks in February 2008, but he had already been heavily involved in informal U.S.-Chinese negotiations about global warming for some time. Was he simply wrong about the real attitude of the Chinese government? Probably not. He did say that China would sign up to a global climate deal "within three to five years of the United States making the transition from laggard to leader," after all, and that period has barely begun.

What went wrong at Copenhagen was probably the consequence of a series of incidents, not the result of a carefully laid Chinese plan. The Chinese were on the defensive from the first because of Western strong-arm methods (as epitomized by the Danish text), and their sense of losing control can only have grown as their formerly reliable allies in the G77 started to waver in their allegiance. By the end of the second week, the American delegation, aware that there was nothing left to do but allocate the blame for the Conference's failure, began to brief against the Chinese. The Chinese duly responded with bad behaviour of their own.

This is not to say that they "lost their temper," or anything as childish as that. Rather, bad behaviour and some deliberate provocations by the West created an opportunity that was exploited by those elements within the Chinese regime who believe that unrestricted, high-speed economic growth—and to hell with the climate consequences—provides a better guarantee of regime security over the long run than holding the temperature down. Much anecdotal evidence by foreign interlocutors of the regime (like Holdren, above) testifies that the growth-at-all-costs crowd are a minority within the senior leadership, but they are not an insignificant minority. At Copenhagen, they got an opportunity to stick a spoke in the wheels, and they seized it. It remains to be seen whether they will be able to establish a longer-term domination over Chinese policy, but it seems unlikely.

> The city of Copenhagen is a crime scene tonight, with the guilty men and women fleeing to the airport. There are no targets for carbon cuts and [there is] no agreement on a legally binding treaty.
>
> —John Sauven, executive director of Greenpeace U.K., December 18, 2009

> The meeting has had a positive result, everyone should be happy. After negotiations both sides have managed to preserve their bottom line. For the Chinese this was our sovereignty and our national interest.
>
> —Xie Zhenhua, head of the Chinese delegation, December 18, 2009

The last day at Copenhagen was a drive-by shooting by countries that had not made any commitments under the process, and the only thing left standing at the end was the pathetic Copenhagen accord, which was in some ways a step backwards from the widely despised Kyoto accord. The sense of betrayal among the thousands in the Bella Centre who had worked for two years to produce a more just and effective outcome at Copenhagen was very great: they didn't even know that the Americans and the Chinese had abandoned the process and cut a side deal until President Obama announced that deal as if it were the legitimate outcome of the Conference. In the early hours of Saturday morning, December 19, 2009, after the guilty men and women had left town, the final full plenary session of the Conference came very close to repudiating the Obama-Wen deal.

For the first time, it became clear that the old common front between the rapidly developing countries like China and India and the great mass of the poorer countries had finally broken down: the latter finally understood that their interests really were not the same. The chairman of the meeting, Prime Minister Rasmussen, gave the closing session just one hour to debate the U.S.-Chinese deal, but he lost control of the meeting as delegate after delegate from what used to be called the Third World, even from countries with left-wing governments that have aligned themselves closely with China, rose to condemn the Copenhagen accord as worse than no agreement at all while the Chinese sat mute in the hall.

"International agreements cannot be imposed by a small group. You are endorsing a coup d'état against the United Nations," raged the head of the Venezuelan delegation. "We're offended by the methodology," said the Bolivian delegate. "This has been done in the dark. It does not respect two years of work." Only a last-minute intervention by the British, Americans and Australians, who called for an adjournment and used it to bundle the hapless Rasmussen out of the chair, prevented the Copenhagen accord from being formally rejected by the plenary. During the recess, they managed to negotiate a last-minute compromise in which the accord was neither accepted nor rejected. It was simply "noted." And with that, everybody went unhappily off to bed and thence to the airport.

But the harsh truth is that, even before the crisis on the last day, the Copenhagen Conference was not on course to adopt a target that avoided crossing the two-degree threshold. The members of the European Union had offered 20 percent cuts on their 1990 emissions by 2020, with the option of going to 30 percent cuts by that time if other developed countries were willing to do the same. The new Japanese government was offering 40 percent cuts by 2020, although it had clearly not yet figured out exactly how this was to be accomplished. Even the United States was offering 4 percent. The Australians and Canadians were following in the wake of the Americans, and would probably accept a higher target if Obama subsequently managed to raise it in the United States. And all of that, plus some carbon intensity reductions by China and India, would still have resulted in an average global temperature three degrees Celsius higher, according to a confidential assessment produced for the arriving heads of state on December 17 by the United Nations secretariat. The hijacking of the Conference by the uncommitted countries on the last day meant that none of these offers remained in the final document, but they weren't enough anyway.

According to a study by the U.K. Met Office released during the Conference, anthropogenic greenhouse gases would have to peak by 2018 and fall by 4 percent a year thereafter in order for there to be a 50 percent chance that the warming will not ultimately exceed two degrees Celsius. Let things slip so that the peak came just two years later, in 2020, and global emissions by human beings would have to fall by 5 percent a year thereafter to have that same 50 percent chance of not crossing the threshold. As Vicky Pope, head of climate science at the Met Office, put it, "If you go to 2025 before peaking, it's virtually impossible to stay under two degrees Celsius." On present form, the chance that emissions will peak before 2025 is approximately zero.

There is no shortage of people, confronted with a spectacle of human misbehaviour like the Copenhagen Conference, who leap to the self-dramatizing conclusion that if this is the best that human beings can do when faced with a really major challenge, then we probably don't deserve to survive. It is hard to excuse a process as clumsy, and occasionally as ugly, as the horse-trading and arm-twisting that went on at Copenhagen, but that is how human politics works. We are not demigods who walk the Earth. We are a mammalian species of no great antiquity that evolved to live in bands of a few dozen or hundred, each of them perpetually at war with all of its neighbours, and we have had to travel a long way in a short time. We haven't actually done all that badly.

Our first task, in this civilization we began to create some ten thousand years ago, was to learn to live together in groups a thousand times as big as the familiar hunter-gatherer bands. For almost all the history of civilization, our only way of managing such large groups was tyranny, and slavery and war were universal. But these ugly features of mass civilization turned out not to be eternal: in little more than two centuries tyranny has become the exception in mass societies, not the rule, and slavery is gone almost everywhere. However, the principle of equality and the rise of democracy did not put an end to political struggle. On the contrary, the number of contending groups within the state has expanded almost continuously, and the politics of deciding who gets what is generally an unedifying spectacle. All that keeps the struggle in most nations within bounds is a certain sense of shared identity, and a set of rules that applies to everybody, rich or poor, strong or weak.

Any solution to the global warming problem requires an international society that is also based on equal rights and bound by law, since emissions anywhere affect everybody. Unfortunately, the effort to create a legal framework of rights and responsibilities in international society got underway much later than the same enterprise within national states. It was driven mainly by the growing need to bring large-scale war under control, and it is still a work in progress.

Seventy-five years ago there were only about fifty independent countries in the world, and more than half of the human race lived in somebody else's empire. The one existing international organization with any pretensions to global authority, the League of Nations, had collapsed, and we were entering the worst war in the history of humankind.

By the 1960s, things had changed a lot. There was a new, more ambitious global organization, the United Nations, created mainly to prevent more such wars, and in particular, nuclear war. There were a hundred independent countries by then. Many of them were dictatorships, but they did represent the interests of their people better than the empires. The world was divided ideologically between East and West and economically between North and South, but the realization was dawning that in some sense we were all in the same boat—and in the end we did avoid nuclear war.

There were 192 governments at the Copenhagen Conference. Most of them are democratic, and they *know* that we are all in the same boat. That's why they were there, and why (within limits) they were prepared to listen to one another. For the first time in history, thanks to climate change, we have full-spectrum global politics with a considerable element of popular involvement—but it is proving to be as messy and incoherent as democratic politics at any other level. Surprise.

The human race is dealing as best it can with threats that require a global response, but we bring our old political habits with us. These habits produced chaos and failure at Copenhagen, and so more time has been lost even though we are running out of time. Some kind of international agreement to combat global warming that addresses most of the key issues will probably be cobbled together over the next few years, because all the major governments understand that it is necessary—but it will be late, it will be far from perfect, and as a result many bad things will happen. Maybe in another century we will have an international society that can respond rationally and rapidly to emerging dangers, but we don't have it now.

We are not going to meet the deadlines set by the real world, and you can't negotiate with physics. So it is just as well that we have some geo-engineering techniques in reserve. We are probably going to need them.

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SCENARIO SEVEN:
CHINA, 2042

Today, most of the work on the security implications of climate change assumes that they will happen elsewhere . . . but actually there will be very real security consequences here, in the U.K., and in other developed nations . . .

If the environment is changing very rapidly and government-policy responses are not keeping up with it, then people may lose confidence in the government's ability to protect them . . . There'll be some people who believe the government aren't going far enough in their changes . . . but there will also undoubtedly be a segment of the population who believe that the government are going too far . . .

If we look at some of the more extreme social and environmental groups that exist currently in Britain—I'm talking primarily about animal rights activists—then, as the changes begin to happen, these people may become more and more radicalized around environmental issues. We may see a rise in non-violent direct action, and, potentially, some of these groups turning to terrorist-type tactics in the extreme. We've seen this sort of thing in America, where, perhaps unfairly, many groups have been labelled eco-terrorists. It's something I know the FBI are very concerned about.

—Chris Abbott, Oxford Research Group

The Deep Ecologists and the Zero Footprinters are understandably furious when anyone suggests that the Toba Winter was a consequence of their policies, because nothing could have been further from their goals, but it is hard to deny that there was a causal connection, however unintended. They are even angrier when their name is mentioned in the same breath as the eco-terrorists, whom they rightly denounce, but in political terms there is a link there, too.

A decade of large-scale terrorism in the 2030s has pushed many Europeans and North Americans into a crude and paranoid world view that lumps all "terrorists" together as an irrational, even inexplicable, phenomenon that is simply "evil." The same phenomenon was observed in the earlier panic about terrorism in the first decade of the century, particularly in the United States, and it was not conducive to clear thinking and sound policy then, either. But there is an important difference between eco-terrorist attacks and those carried out by terrorists from the formerly oil-rich countries of the Middle East.

The bombing of the Tunisian terminal for the cables carrying power from the Saharan solar arrays to Europe in 2031, for example, was certainly terrorism, but there was virtually no ideology involved. Interrogation of the surviving attackers, all from the Gulf countries that had been devastated economically by the collapse in the demand for oil, suggested that simple rage at the evaporation of the prosperous future they had expected for themselves was their primary motive.

The twelve-person team who attacked the Number 2 reactor at Penly in Normandy in 2032, on the other hand, were genuine eco-terrorists. They were native-born French citizens (and one Belgian), well-educated and leading comfortable lives, whose motives were specifically ecological and ideological.

The horrors that ensued when the main plume of radiation from the burning reactor enveloped Paris have made them monsters in popular memory, but the investigation made it clear that they were motivated by profound opposition to many of the measures that had been adopted to fight climate change. Their hostility to the spread of nuclear power as a substitute for fossil fuels was only a symbol of a much broader disaffection. (Ironically, the Penly reactors, which had run continuously for over forty years, were due to be decommissioned only three months after the date of the attack.)

The distinction is important because terrorists coming mainly from what used to be the oil-rich countries of the Middle East are easily profiled, must make their way through heavily fortified borders, and cannot carry advanced weapons. They do not easily find support among Muslim Europeans, who are mostly descended from immigrants from Turkey, North Africa and Pakistan. As a result, their attacks have mainly been directed not at Europe but at the softer targets of Egypt, Libya and the Maghreb, whose lucrative deal to sell solar power to the European Union excites anger and resentment among the destitute and desperate populations of the formerly oil-rich states.

The eco-terrorists, however, are already inside Europe's borders, and their motives are so far removed from normal politics that they could be anybody. Unusually for a terrorist movement, their activists include almost as many women as men (like the old Baader-Meinhof Gang, which they somewhat resemble in spirit although not in ideology). And as citizens of a technologically advanced culture, they have access to serious weapons: the Penly attackers used infrared cloaking devices, UAVs coming from the opposite direction to confuse the reactor site's defences, and deep-penetrator man-portable missiles with a two-thousand-metre range. Moreover, their sympathizers are everywhere: their weapons must have come from supporters in the armed forces, and they may have had a collaborator inside the Penly site who took the movement detector system off-line about ten minutes before the attack. (Since nobody in the control room survived, this has never been confirmed.)

The eco-terrorists are not simply anti-nuclear extremists. They have their roots in the great debate that split the West in the teens and twenties. On one side were those who wished to retain as much of the old way of life as possible, solving the "climate-change problem" by a combination of conservation measures and various technological fixes, such as carbon capture and sequestration (CCS) and more nuclear power. On the other side were those who argued that the old way of life *was* the problem and that far more radical changes were necessary.

It would be unfair to characterize those on the "right" (as they were inevitably called) as stubborn technophiles. Most had switched to an electric car or no car at all, and accepted even radical conservation measures, such as the cuts in air travel, as necessary. They simply argued that the current density of population could not be maintained without very large amounts of energy—so technological fixes in the energy sector were absolutely necessary.

The "left," similarly, were not all anti-technological Luddites. The great majority were people who just wanted to shift the emphasis further towards conservation, who did not want any more coal-fired power stations, even with the promise of CCS, and who hated nuclear energy. They had rational reasons for that—few people on either side of the argument were entirely comfortable with nuclear power—but there was also a strong emotional component dating all the way back to the anti-war movement of the twentieth century. Anti-nuclear power was the one issue that united all the disparate strands of the left, and so it got a lot of play.

> Coal-fired and nuclear and gas-fired central power plants are all dying of an incurable attack of market forces . . . Basically what happened is that central plants cost too much and have too much financial risk to be attractive for private capital . . . That's why, in 2006, [the nuclear industry] worldwide installed less capacity than solar cells added; a tenth as much as wind power added, thirty or forty times less than all forms of micro-power. Just

> distributed renewables got US$56 billion of private risk capital, nuclear got zero; it's only bought by central planners. There are no orders in the United States, despite subsidies now roughly equalling or exceeding the total cost of the (nuclear) plants.
>
> —Amory Lovins, cofounder, chairman and chief scientist, Rocky Mountain Institute

> The people in the Department of Energy have done everything possible to block decentralized power. All those civil servants know that when they retire there'll be a job for them on the board of British Nuclear Fuels. They know Greenpeace isn't going to give them £40,000 a year for doing two days a week on the bloody board, so they're covering their arse for their future, and advising ministers accordingly. [If Greenpeace could offer them the same kind of money, they'd] most probably change their bloody advice.
>
> —Ken Livingstone, former mayor of London, 2000–08, interview in *The Observer,* March 23, 2008

Neither side really lost the long argument that divided both Europe and North America from about 2015 onwards, in the sense that both conservation and techno-fixes played a large part in the emissions-cutting strategy of every major Western country. But the left felt that it had lost, because almost all the larger countries launched major programmes for building new nuclear reactors during the 2010–2015 period—perhaps because they had concluded that coal plants plus CCS were going to be even more expensive than nuclear power, or maybe for other reasons. ("Other reasons" was the answer strongly favoured on the left, which was greatly embittered as a result.) By the early 2030s, nuclear power plants had sprung up almost everywhere that there was adequate water for cooling the reactors—so while only a tiny handful of extremists ever resorted to violence, they enjoyed a certain sympathy from much larger numbers of people on the left.

That sympathy temporarily evaporated after the Penly disaster, but it revived as the evidence accumulated that the West's strategy on climate change was not working. Oil consumption was down to a fifth of its peak in the early twenty-first century, a large number of coal-fired power stations had been replaced by nuclear plants, a lot of people had made a lot of money out of fighting climate change—but carbon dioxide was already at 480 parts per million by 2035, with much more to come, and killer heat waves were striking Europe and the American Midwest and Southwest several times each summer. Methane was bubbling up out of the permafrost, the oceans' ability to absorb carbon dioxide was down by 70 percent from the 2005 figure, and the Greenland glaciers were sliding into the sea so fast that you could almost see them move.

Those who had argued many years before that the West should aim for even deeper cuts in its emissions in order to draw the emerging industrial countries into a global agreement had been proved right—and they were mostly on the left. On the other hand, the milk had been spilt long ago, and it was too late to go back to that solution now: emergency measures were needed promptly, if a whole series of climate tipping points were not to be passed. So the political struggle in the West moved on to the next stage, with many on the right arguing that it was time to resort to last-ditch geo-engineering measures to cut down the amount of solar radiation reaching the Earth's surface and so keep the temperature down, and many on the left reacting with horrified rejection.

Some form of geo-engineering intervention to reduce global temperature by a degree or so was already being advocated by countries of the "Majority World" (most of Asia, Africa, and Latin America), not as a permanent solution but at a stopgap measure to prevent the climate from passing some critical tipping points while the human race struggled to get its emissions down. It was the countries of the former Third World that took the lead in this because, being nearer to the equator, they were already suffering severe losses from storm damage, rising temperatures and collapsing agriculture. But the atmosphere is a single, shared resource, so they could not legitimately interfere directly with the climate system unless the West also agreed—and the West did not.

> Many members of the scientific and technical communities fear that the full effects of various geo-engineering schemes are not fully understood. The failure of the ambitious Biosphere 2 facility is one example of a complex project that was unsuccessful because scientists still have a limited understanding of how earth systems work together; the implications for a failed project of global scale are frightening, and as a result policy-makers are hesitant to embrace various geo-engineering schemes for combating the effects of global warming.
>
> Other criticism comes from those who see geo-engineering projects as reacting to the symptoms of global warming rather than addressing the real causes of climate change. Because geo-engineering is a form of controlling the risks associated with global warming, it leads to a moral hazard problem. The problem is that knowledge that geo-engineering is possible could lead to climate impacts seeming less fearsome, which could in turn lead to a weaker commitment to reducing greenhouse-gas emissions. It could be argued that pursuing geo-engineering solutions sends the message that humans can continue to live out of harmony with the Earth as long as we have enough clever technological solutions to preserve human life. This disregard for the overall health of Earth's ecosystems and natural environments is an affront to proponents of sustainable development.
>
> —Wikipedia, "Geo-engineering" entry, as of June 3, 2008

Many individuals in the West, perhaps a majority, did agree that it was time for desperate measures. However, the fundamental principle that made a relatively civil dialogue between left and right on climate issues possible in most Western countries was an agreement to avoid raising the question of geo-engineering measures. When a few American, British and Spanish politicians dared to break the taboo in 2037, terrorist micro-bombings of long-haul airliners suddenly resumed after a long hiatus. The politicians quickly shut up again. Urgent though the situation was, Western governments were simply paralyzed, fearing that an open debate on geo-engineering would trigger what amounted to a low-level civil war, so they did nothing.

The Majority World couldn't wait. Having allowed a decent interval for the West to sort out its own internal divisions and begin an international discussion of how much geo-engineering of what kind was needed, and how soon, it acted unilaterally. On March 25, 2039, Indonesia and the Philippines began releasing the high-altitude balloons that would place approximately one megatonne of sulphur per year into the stratosphere, in order to drop the planet's surface temperature by two degrees.

It was not a very dramatic sight: five or six giant balloons a day, each carrying a payload of about five tonnes, disappearing rapidly into the sky from each of a hundred different sites scattered across the two island nations. The spread of latitudes both north and south of the equator ensured that the sulphur dioxide was released into the tropical upward branch of the stratospheric circulation in both hemispheres. Within months, it would be distributed throughout the stratosphere in all parts of the world, now broken down by chemical processes into submicrometre-sized sulphuric acid droplets that reflected sunlight back into space and cooled the Earth's surface. It was some days before the West even realized the scale of what was going on.

It was China that had bankrolled the operation and supplied a lot of the equipment, of course, although Indonesia, at least, would have been capable of doing it alone: the technology was not at all demanding and the annual cost was only about US$25 billion. Because it was being hit even harder by climate change than the two tropical countries, China had the most urgent need and had taken the lead. It also had the military power to ensure that nothing bad happened to the two smaller nations if the Western or Japanese reaction should take a violent form.

In fact, while Western governments greeted this unilateral Asian action with loud protests, most were secretly glad that the Chinese and their allies had acted decisively and broken the stalemate imposed on the world by Western ideological divisions. The Chinese assured everybody that they were monitoring the effects of injecting such large amounts of sulphur into the stratosphere and would stop the process at once if there were unforeseen adverse effects, after which the atmosphere would return to normal in about a year. Besides, they were only seeking to replicate the cooling effect created by natural volcanic eruptions that boosted comparable amounts of the same substances into the stratosphere. What could go wrong?

Elements of the left in many Western countries demanded that their governments use force to stop the "dangerous experiment," but even in the few countries where the left controlled the government, nobody seriously contemplated war with China. It might be a dreadfully crippled giant after the beating it had taken from the climate in the past decade, but it was still a giant. Moreover, many people on the left were secretly curious to see if this kind of geo-engineering could solve the problem that dominated their lives and threatened their futures.

For a year and a half, the balloons rose every day, and by late 2040, a pronounced cooling effect was clearly evident all around the planet. It wasn't all the way back to the "normal" of the late twentieth century, but it was like being back in the 2020s again. Then Mount Toba erupted.

It was a mere burp compared to the last major eruption of the Toba supervolcano seventy-one thousand years ago, which boosted an estimated 3,000 cubic kilometres of ash into the stratosphere and caused a "volcanic winter" of three to six years' duration. That one had left a caldera one hundred kilometres across in the middle of northern Sumatra, but this time the volcano merely cleared its throat. Only about 550 cubic kilometres of ash ended up in the stratosphere, no more than three times the amount that had been produced by the explosion of Mount Tambora, at the other end of what is now Indonesia, in 1815. But that was enough.

The Tambora explosion in 1815 had caused the "Year Without a Summer," in which crops failed all over the world and hundreds of thousands, perhaps millions of people starved—all this despite the fact that the explosion actually lowered average global temperature by less than one degree Celsius. The Toba eruption in 2040 lowered the temperature in the temperate zones of the planet by almost two degrees Celsius—and that came on top of the two degrees of cooling that the Chinese and their allies had just achieved by their geo-engineering work. They immediately stopped their work once Toba erupted, of course, but they couldn't undo the effects at once, so during 2041, the world's surface temperature was on average four degrees Celsius colder that it had been the year before—and fully two degrees colder than it had been in 1990. The harvests failed almost everywhere.

There would have been serious problems with the food supply even if Mount Toba had erupted at this scale in 1990, but as the climate changed during the following half-century, crop varieties had also been changed to ones better suited to the hotter conditions—and of course they didn't respond very well when it suddenly got four degrees Celsius colder. World grain production dropped by 35 percent, and despite a mass slaughter of animal herds that summer in an attempt to free more grain for human consumption, when the Northern Hemisphere winter arrived there simply wasn't enough grain to provide all nine billion people with their minimum daily caloric intake.

No more than three to four hundred million people died directly from starvation, almost all of them in the poorer countries of the tropics and subtropics. However, the political violence and social breakdown engendered by this extreme emergency affected even the most stable and prosperous countries, while regions containing about a third of the world's population just slid into "failed state" status. Although the average global temperature returned to normal (the new normal, that is) by the following year, at least as many people as had died in the famine would be killed in the following five years from the second-order consequences of the "Toba winter": civil war, mass migration and genocide.

In the West, the calamity of 2041–42 merely deepened the existing ideological split. The left argued that it proved they had been right all along: geo-engineering was a dangerous technology that must never be tried again. The right insisted that it had just been an unfortunate coincidence, and indeed that humanity needed a battery of geo-engineering techniques to cope with what the world threw at it. (There were, of course, bitter disputes about how much of the damage had been caused by the human intervention and how much by the eruption.) But in the aftermath of the disaster, the left had the wind in its sails, and governments throughout the West fell into their hands.

Which brings us to the current impasse. Global warming will reach plus three degrees Celsius by 2050, and everyone on the right and many on the left believe that we are on the brink of various tipping points if, indeed, we have not already passed them. Even the radical further reductions in emissions mandated by the new governments, aided by the collapse of emissions in some newly failed states, cannot possibly halt the rise in temperature fast enough to stop us short of those thresholds. Yet geo-engineering is profoundly discredited, and several major Western powers have let it be known that any country that attempts to intervene in the climate unilaterally will face an attack with nuclear weapons.

God help us all.

> The problem from a game-theoretic perspective of cutting emissions is that you have to get everybody to comply. With geo-engineering you have the opposite problem: you want to get everybody to *not* jump on the bandwagon.
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> When we think of geo-engineering now, we tend to think about a huge, rich, technocratic power like the U.S. being the one that does this, but some of these schemes might be within the reach of the richest individuals on the planet; easily within the reach of quite poor national governments. So, in fact, you might find that a national government like, say, Bangladesh, at some point when they are really going underwater, says I'm not really very interested in all you rich countries moralizing. I just want to turn down the heat and do it *now*. And different people might have different views about how to turn down the heat, and whether Bangladesh was allowed to do that, and that could lead to international conflict.
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> I think there are questions about whether we should start thinking about what the norms of international control are. Whether we need some kind of international treaty process perhaps, and it's better to think about that before we're forced to make decisions, than to think about that in some chaotic way after some country decides they want to do it unilaterally.
>
> —David Keith, Canada research chair in energy and the environment, University of Calgary

CHAPTER SEVEN
Emergency Measures

Recent research has shown that the warming of the Earth by the increasing concentration of CO_2 and other greenhouse gases is partially countered by . . . sulfate particles, which act as cloud condensation nuclei . . . [Human-caused] sulfate particle concentrations thus cool the planet, offsetting an uncertain fraction of the [human-caused] increase in greenhouse gas warming . . . [so cleaning up industrial pollution and eliminating the sulphur dioxide emissions] could lead to a . . . global average surface air temperature increase by 0.8 degrees C per decade on most continents and 4 degrees C in the Arctic. Further studies . . . indicate that global average climate warming during this century may even surpass the highest values in the projected IPCC global-warming range of 1.4–5.8 degrees C.

By far the preferred way to solve the policy-makers' dilemma is to lower the emissions of the greenhouse gases. However, so far, attempts in that direction have been grossly unsuccessful. While stabilization of CO_2 would require a 60–80 percent reduction in current anthropogenic CO_2 emissions, worldwide they actually increased by 2 percent from 2001 to 2002, a trend which will probably not change . . . Therefore, though by far not the best solution, the usefulness of artificially enhancing Earth's albedo [ability to reflect sunlight] might again be explored and debated as a way to defuse

> the Catch-22 situation just presented and counteract . . . growing CO_2 emissions. This can be achieved by burning sulphur or hydrogen sulphide, carried into the stratosphere on balloons and by artillery guns to produce sulphur dioxide.
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> —Paul Crutzen, "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" in *Climatic Change*, August 2006

Paul Crutzen is a Nobel Prize-winning atmospheric chemist who risked his entire reputation by suggesting, in the now famous article originally published in *Climatic Change* in 2006, that it might become desirable or even necessary to put sulphur dioxide into the atmosphere in order to raise the planet's albedo and thus to avoid runaway climate change. In doing so, he quite deliberately re-opened the public debate on the taboo subject of geo-engineering. Showing considerable tactical skill, he backed into it rather than tackling it head-on.

For most of the time since the Industrial Revolution, he pointed out, human beings have been putting excess carbon dioxide into the atmosphere, which caused warming, but those same industrial processes that burned fossil fuels also emitted sulphur dioxide and other pollutants, which reflected sunlight back into space and caused cooling. This "fortunate coincidence" meant that the sulphur dioxide cancelled out some of the warming effect of the carbon dioxide: between 25 and 65 percent of it, according to Crutzen's own estimate in 2003, but possibly even more according to a rival estimate by T. L. Anderson in the same year. But those days are coming to an end: new laws in almost all the developed countries are compelling industries to stop emitting sulphur dioxide, which the World Health Organization estimated was causing five hundred thousand premature deaths annually worldwide.

Thus the "global dimming" of the sulphur dioxide pollution, which had a cooling effect, is being lost, while the carbon dioxide continues to pour forth—and that's a big part of the reason why global warming is accelerating.

Crutzen suggested that we might get around this Catch-22 by replacing the lost sulphur dioxide in a way that did not damage people's health. Rather than put it into the lower atmosphere (troposphere) where people would have to breathe it, we could inject it into the upper atmosphere (stratosphere). Moreover, since small particles tend to remain in the stratosphere for a very long time, we would only have to use a tiny fraction—a few percent—of the huge amounts of sulphur dioxide that we used to pour heedlessly into the lower atmosphere (where any given particle of sulphur dioxide remains aloft for only a week or so) in the bad old days. But even though Crutzen carefully couched his proposal in terms of substituting a less harmful intervention in the atmosphere for an extremely harmful one that we had been doing inadvertently for over a century, he would probably have been lynched if his Nobel Prize (for his work on the ozone hole) had not afforded him some protection.

The rage that geo-engineering proposals stirs in some quarters can only be compared to the fury that suggestions for expanding nuclear power arouses (often in the same quarters), and Crutzen got his full share of it. Like all scientists who venture into this minefield, he was careful to present his proposal in the journal *Climatic Change* purely as a last-ditch technique for halting global warming if it were racing out of control: " . . . [A]gain I must stress here that the albedo enhancement scheme should only be deployed when there are proven net advantages and in particular when rapid climate warming is developing, paradoxically, in part due to improvements in worldwide air quality. Importantly, its possibility should not be used to justify inadequate climate policies, but merely to create a possibility to combat potentially drastic climate heating." But nothing he said helped, because in the eyes of others, including many of his fellow scientists, he was creating a "moral hazard."

The phrase comes from the financial world, where it is argued that governments should not bail out investors who are about to lose their shirts on some misconceived project, no matter how great the political pressure, because to do so simply encourages more reckless behaviour by other investors who expect that their wildly speculative investments will be similarly rescued if things go wrong. In the world of climate-change science, the moral hazard is that if people (and governments) believe that there is some magic bullet that can stop climate change through technological wizardry, then they will lose their motivation to address the problem the hard way, through reducing their greenhouse-gas emissions. Geo-engineering must not be discussed in front of the children, because if they know about it they will behave badly. Although a few of the most respected climate scientists take a quite different tack.

> The human burning of fossil fuels is geo-engineering. The suggestions that we encourage re-forestation and the use of bio-char and the storing of carbon in the soil—they're geo-engineering, but they're of a fairly natural order, and they have multiple benefits, so nobody would object to those. There are other, more extreme geo-engineering things that we could do—and I say we should of course do all the other things first—but you may get to a point where you see the ice-sheets are on the verge of collapsing. Then you have to consider these other possibilities.
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> I think the one that Paul Crutzen and others suggested—putting sulphur dioxide into the stratosphere so it forms sulphuric acid droplets, a human-made volcano, in effect—[is an interesting idea]. You might say that's dangerous, because we don't know what's going to happen, and to some extent that's true even for Crutzen's

> suggestion, but nature has performed that experiment. The Mount Pinatubo eruption in 1991 is interesting because it was large enough that for one year—that one year after the eruption—it was reflecting back to space about four watts of energy per square metre.
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> That's [cancelling out the equivalent of] doubled carbon dioxide, [the] equivalent of 560 parts per million of carbon dioxide. It's a big negative forcing.
>
> One interesting point about it is that if you look at the melting in Greenland for the period when we have data, which began with satellite measurements in 1978–79, until the present, so thirty years, the year with the least melting was 1992, when those aerosols had maximum optical thickness. The sunlight has to go through them at a slant angle to hit this high-latitude ice-sheet, and it reflected enough sunlight away that it minimised the melting. So if the concern becomes especially these ice-sheets and their impact on sea-level, then you may have to seriously consider that. But frankly it makes more sense to reduce the forcing that's causing the problem.
>
> —James Hansen, director,
> NASA Goddard Institute for Space Studies

There is good reason to be cautious when it comes to geo-engineering, because the moral hazard is real. Prolonged reliance on geo-engineering techniques to keep the global temperature stable while carbon dioxide concentrations continue to rise would probably have catastrophic effects on life in the oceans, which are already becoming distinctly more acidic due to a higher level of dissolved carbon dioxide in the water. (In the water, carbon dioxide turns into carbonic acid, which is what rots your teeth when you drink too many soft drinks.) Too much acidity, and the tiny marine animals that are at the bottom of the food chain have more and more difficulty in forming their shells.

As a very long-term solution to the problem of global warming, geo-engineering techniques for holding the temperature down are time bombs, because over time, as more and more carbon dioxide accumulates in the atmosphere, the difference between the actual average global temperature, artificially lowered by geo-engineering, and the temperature that the existing concentration of carbon dioxide would normally imply grows wider and wider. All of these techniques require continuous supervision and continual inputs of energy and materials from a highly organized society. If a major war, plague or other event causing social breakdown should lead to an interruption in the service, then there would be a sudden jump in the global temperature of three, four or even five degrees (depending on how long the dependence on geo-engineering had been), and an equally sudden collapse of almost all agricultural systems. Hardly any domesticated plants could withstand a sudden shift in temperature on that scale .

But nobody is actually proposing geo-engineering solutions as an alternative to cutting greenhouse-gas emissions. They are generally seen by their advocates as temporary devices for winning time and keeping the temperature from rising into the dangerous zone of uncontrollable feedbacks *while work continues to get emissions down to a safe level*. As for the moral hazard involved in discussing these techniques in front of the children, it's too late. The children already know. Indeed, the danger is that they may have too much faith in the ability of geo-engineering techniques to save them from their own folly.

> The thing that most of us want to see happen is to cut emissions quickly enough that the climate change is small enough that we just live with it, but the actual amount of climate change we get for a given amount of emissions is still deeply uncertain. It's been uncertain for forty years, since President Johnson got the first high-profile report on

the climate problem when I was a boy, and it's still uncertain. We're not going to know how big the climate threat is until after it's too late; until after we've put the carbon dioxide into the air.

Say it's 2050, and maybe we've actually done a great job of cutting emissions, and maybe emissions are well on their way down at that point, and concentrations [of carbon dioxide] have peaked at some level, but we still find that we're melting the Greenland ice sheet, which is something that might happen. Then we might find that we wanted to stop it. That would not be using the techniques of geo-engineering *instead of* cutting emissions; it would be *as well as* cutting emissions, to minimize the worst effects . . .

The biggest concern with geo-engineering—whether or not we should talk about it, whether or not we should do any research now—is that the mere knowledge that it could be done will reduce the incentive to cut emissions now. The short answer is simply that the cat is out of the bag. You can't make good policy by hiding your head in the sand. At this point, what we have is a sort of blogosphere around geo-engineering, with an enormous number of people talking about it, and very little in the way of good research. It might be that none of the geo-engineering techniques we have actually work . . .

Let's be clear: none of these schemes are an exact compensation for not emitting carbon dioxide. All of these schemes we have for engineering the planetary heating balance, if you like, will have some negative consequences. Perhaps very serious ones, perhaps not so serious. So I think a research programme aimed at understanding how we do it and what the consequences are is better than the current situation, where we agree that it's politically incorrect to talk about it, but everybody sort of knows it can be done and perhaps

> overestimates how much it can be done. I think that's more dangerous than real knowledge.
>
> —David Keith, Canada research chair in energy and the environment, University of Calgary

The avalanche was waiting to happen anyway, but it was Paul Crutzen's article in 2006 that set it in motion, and now there are half a dozen different proposals on the table that could reasonably be called geo-engineering. Most of them fall into two main categories: fast-acting techno-fixes that directly reduce the amount of solar energy reaching the Earth's surface, and slower processes for extracting carbon dioxide from the atmosphere. On the assumption that you can handle this knowledge without immediately emitting immense amounts of carbon dioxide, I will attempt a brief survey of the field.

Crutzen's proposal was far from the first time that somebody had suggested mimicking the action of volcanoes, which also inject large amounts of sulphur into the stratosphere, but he brought two new things to the table: a rough costing of the enterprise, which he reckoned would be equivalent to 5 or 10 percent of the current U.S. defence budget, or US$25–50 billion annually, and some tentative reassurance on the question of whether doing this on a long-term basis would damage the ozone layer. While sulphur dioxide does not directly attack ozone, in the presence of chlorine compounds (derived from the chlorofluorocarbons [CFCs] that caused the ozone holes in the first place), it acts as a catalyst and speeds up the destruction of the ozone in the stratosphere. However, Crutzen estimated, by the time that anybody would feel driven to resort to this kind of emergency measure, decades from now, the amount of CFCs in the upper atmosphere will have fallen to levels that do not significantly endanger ozone concentrations, even if sulphur dioxide is present as well. The Montreal Protocol of 1987 has done its job, and CFC emissions are almost at an end now.

Since Crutzen's Nobel Prize was directly related to his work on ozone chemistry in the stratosphere, his estimates carried considerable weight in the scientific community. Moreover, his alternative, less articulated proposal for blocking sunlight by dispersing elemental carbon (soot) in the stratosphere actually promised to raise stratospheric air temperatures, thereby inhibiting the formation of the ice-crystal clouds where massive amounts of ozone get destroyed in the late winter each year. Others have subsequently pointed out that the sulphur dioxide need not be sent up into the stratosphere by the cumbersome means of balloons (resembling giant weather balloons, presumably) or artillery. It could also be delivered to the stratosphere simply by dosing jet aircraft fuel with a 0.5 percent solution of sulphur, which would lower the cost of the operation by an order of magnitude. This was the method favoured by Professor Tim Flannery of Macquarie University in Sydney, leading climate scientist and Australian of the Year 2007, who observed in May 2008 that climate change was moving so fast that it might be necessary to start doing this within five years. An alternative delivery method, not so hard on aircraft engines, would be to use giant mid-air refuelling aircraft like the USAF's KC-10 Extender, filling their tanks with sulphur dioxide or hydrogen sulphide gas under pressure. Nine aircraft flying three sorties a day, according to the calculations of Professor Alan Robock of Rutgers University, would be enough to deposit a million tonnes of sulphur in the stratosphere each year. The cost? A couple of billion dollars.

The sulphur-in-the-stratosphere idea, which has the legitimacy of mimicking a natural process and requires no new technology, has a huge lead over all rival proposals for cutting incoming solar energy. According to a recent estimate, one kilogram of well placed sulphur in the stratosphere would roughly offset the warming effect of several hundred thousand kilograms of carbon dioxide. The competing proposals all envisage some form of physical sunshade, whether by spraying a myriad of tiny, shiny balloons into the stratosphere or boosting a huge cloud of light-refracting mini-spacecraft (sixty centimeters in diameter, weighing about a gram each) into a stable orbit between the Earth and the Sun. The latter is intriguing next-generation-but-one technology—and if technological hubris were a disease, then Roger Angel, director of the Center for Astronomical Adaptive Optics at the University of Arizona, would probably be dead.

Angel's idea is to insert his fleet of sixteen trillion gossamer-light spacecraft into the L1 or Lagrange point about 1.6 million kilometres from Earth along the Earth-Sun axis. This is in some ways the equivalent of a geostationary orbit, except that objects put into solar orbit at the L1 point remain directly between the Earth and the Sun without any further expenditure of energy. Sixteen trillion spacecraft sounds like rather a lot, but each one is basically a transparent film less than a metre in diameter, pierced with small holes, that costs very little to produce. Each would weigh about as much as a butterfly, and they would be fired into space in stacks of a million by electromagnetic launchers installed on a mountaintop near the equator. A total of twenty such magnetic railguns, launching a stack of the flyers every five minutes for twenty years, would give Angel his sixteen trillion flyers, which, on arrival at the Lagrange point, would be dealt off the stack into a large, cylindrical cloud with a diameter about half that of Earth but ten times longer.

The cylinder would be oriented lengthwise along the Earth-Sun axis, so that much of the sunlight destined for Earth would pass through a sixty-thousand-kilometre-long cloud of transparent flyers. Each flyer would divert about 10 percent of the light hitting it away from the Earth. The rest of the light would pass through and continue to Earth, while the slight pressure exerted by the solar radiation, manipulated by tiny mirrors that act likes sails, would enable each flyer to maintain its position in the cloud (which would not be that dense, really: the average distance between the tiny flyers would be about a kilometre). Larger, unmanned control craft would send the orders that kept the cloud of flyers in its cylindrical shape.

The net effect would be to reduce sunlight by about

2 percent over the entire planet, enough to counterbalance the heating caused by a doubling of atmospheric carbon dioxide in the Earth's atmosphere. If circumstances on Earth changed and more solar energy was needed, however, the control craft could also let almost all the sunlight through simply by moving the flyers out of their cylindrical formation and spreading them out in a flat lens.

It is wonderfully ambitious technology, and Angel calculates that it could be done in a quarter-century for about a trillion dollars. Like all the people working in geo-engineering, he sees it as a last-ditch proposal: In a *Guardian* interview on May 29, 2008, he said that the "potential side-effects of geo-engineering and the cost of doing it in space would be inhibitors to doing this unless we felt desperate." The only drawbacks are that it costs about forty times as much as Crutzen's proposal, takes twenty-five times as long to complete, and depends on currently unavailable technology. On the other hand, it could be just what the twenty-fourth century needs (if there is a human twenty-fourth century), because if they decide to terraform Mars and Venus, this is probably the most efficient way of lowering the temperature on Venus and raising it on Mars.

Meanwhile, back here on Earth, there are various proposals on the table that would simply remove large quantities of carbon dioxide from the atmosphere. The cheapest and most effective, of course, would be massive reforestation projects in the tropics (deforestation currently accounts for an estimated 20 percent of annual carbon emissions by human beings), but since this is an intensely difficult issue politically, more technological projects for sequestering carbon are also begging for attention. The most successful, at least in terms of attracting public attention, has been the notion of fertilizing the ocean surface with scarce trace elements that normally limit the growth of marine micro-organisms.

In the case of both Climos and Planktos, two California-based start-ups, the scarce element on which they founded their business plans was iron. Very small amounts of this mineral are essential to the growth of the phytoplankton (microscopic plants) that are both the foundation of the oceanic food chain and also, if they die uneaten and sink to the bottom, the main vehicle by which carbon is sequestered in the ocean depths permanently or for very long periods of time. Runoff from the land tends to provide coastal seas with adequate amounts of iron, but in the open ocean basins, the only means of delivery is sporadic deposits of wind-blown dust. Many species of phytoplankton have evolved to take rapid advantage of these occasional bonanzas of iron-rich dust, and hence the brief phytoplankton blooms, lasting about sixty days, that occur in the oceans from time to time.

It was argued that changes in agricultural practice had seriously reduced the amount of wind-blown dust over the oceans since 1980, and that NASA and NOAA (National Oceanic and Atmospheric Administration) studies showed a corresponding decline of 25 percent in Pacific plankton populations since that time (6–9 percent globally). What these companies proposed to do was to replace some of that missing iron by sowing finely powdered iron dust across large tracts of open ocean—Planktos suggested that fifty tonnes would be adequate for ten thousand square kilometres—in order to artificially stimulate phytoplankton blooms. Recent ocean tests suggest that one kilogram of fine iron particles (0.5–1 micrometre) may generate well over 100,000 kilograms of plankton biomass.

The phytoplankton would absorb enormous amounts of carbon dioxide as they grew, and those that survived to the end of their sixty-day life-cycle would then sink to the bottom, carrying megatonnes of carbon down with them. Even those that were eaten by zooplankton (the microscopic animals that multiply almost as fast during a bloom) would serve a useful purpose, as the zooplankton would in turn be eaten by crustaceans and fish, enhancing the biomass of the entire oceanic region.

Much of the world's global carbon fixation takes place in the oceans. Planktos talked grandly on its website about creating "forests in the oceans," and suggested that "ocean iron fertilization (OIF)," as the technique is now known, might eventually restore the annual three gigatonnes of carbon sequestration by phytoplankton that had been lost since 1980 because of the changed pattern of wind-borne dust. If that were true, it would be quite useful, as it is equal to approximately half the current emissions from all human industrial and transport activities in a year. Indeed, the Planktos website boasted that "Returning plankton populations to 1980 levels would neutralize about 50% of industrial society's greenhouse-gas emissions, and we feel that is about all you can or should ask a single ecosystem to contribute to our self-inflicted climate wars."

You will, of course, be wondering where the profit lies in all this (for these companies are financed by venture capital). The answer is that if they could demonstrate that their technique actually generated large phytoplankton blooms that would not have occurred naturally, and if they could show that this did no harm to other chemical or biological processes in the ocean, and if they could prove that the net result of the bloom is to remove substantial amounts of carbon dioxide from circulation for a long time (more than a hundred years), and if they could document and measure just how much carbon dioxide they had moved to the ocean bottom, *then* they could sell that amount of sequestered carbon dioxide as carbon credits. Rather a long string of ifs, and profitability also depends on a global cap-and-trade market that provides a decent price for carbon. (Dan Whaley, founder and CEO of Climos, estimated in 2007 that the cost to the company would be three to seven American dollars per tonne of carbon dioxide that was sequestered.)

As with most geo-engineering schemes, however, experiments with OIF have not been large enough or long enough to yield conclusive answers about the utility, cost and environmental implications of the technique. Much powdered iron has been thrown off the sterns of ships, and local phytoplankton blooms have duly occurred, but the studies that would provide real data, for example, about what proportion of the phytoplankton would sink to the bottom, removing carbon dioxide from circulation, and how much would simply be eaten, have not yet been done. Presumably because the money hasn't been there to do them, and it still isn't.

Indeed, in 2008, Planktos announced that it was pulling the plug on further ocean experiments, called its ship home, and laid off most of its employees. Climos, which has managed to attract some very distinguished scientific names to its advisory board, continues to express optimism about the long-term prospects for the technique, but it is now effectively hamstrung for some time to come. In May 2008, the ninth conference of the 191 countries that have signed the UN Convention on Biological Diversity responded to the demands of a coalition of environmental groups by calling for a moratorium on the practice of adding nutrients to the ocean. Although the moratorium has no legal force, it is a huge deterrent to any further experimentation for the time being.

A different approach to ocean fertilization was taken by the Australian firm Ocean Nourishment Corporation, which proposed on its website to "increase the amount of carbon involved in the naturally occurring organic carbon cycle, through the enhancement of phytoplankton stocks in nitrogen deficient regions of the world's oceans." In these nitrogen-poor areas, mainly near the edges of the continental shelves, the company proposed to release a modest but steady flow of highly diluted urea, a nitrogen-based fertilizer, from underwater pipes in order to encourage the growth of phytoplankton. Not enough would be released to cause algal blooms—only about one-fifth to one-tenth as much—but it would allegedly be enough to support denser populations of phytoplankton, and therefore of other ocean species all the way up the food chain. Overall biomass would increase, and so would the absorption of carbon dioxide and the amount of carbon ultimately sequestered on the bottom. Having documented this process, Ocean Nourishment would then claim carbon credits for the extra carbon dioxide removed from the atmosphere.

Ocean Nourishment's first experiment was to be carried out in the sea between the Philippines and Borneo in 2008, but like Climos it felt compelled to suspend operations by the call for a moratorium. The issue was then referred to the London Convention, the body that regulates the dumping of wastes at sea on behalf of the International Maritime Organization. However, the parties to the London Convention, meeting in late 2008, effectively reversed the ruling, adopting a resolution that underlined the need for further research on OIF and exempted legitimate scientific research on these ocean fertilization techniques from being considered "dumping" of pollution. This left the situation so confused that a joint Indian-German expedition to the Southern Ocean in early 2009 to experiment with OIF on quite a small scale (twenty tonnes of iron dust over three hundred square kilometres of ocean) was cancelled by the German Environment Ministry under strong pressure from environmental groups, only to be authorized once more by the Research Ministry two weeks later.

One may realistically expect other experiments with geoengineering techniques, even on a small scale, to meet with similar opposition. Whether seeking to suppress these experiments is the right thing to do is quite a different question, and one whose answer is not clear. Intuitively, one suspects that there are more cost-effective and less invasive ways to sequester carbon than OIF, but intuition is not always a good guide in scientific matters, and it could be useful to know more about what is or is not possible.

A good example of the shortcomings of intuition is the seemingly preposterous idea of machines that would draw carbon dioxide out of the air directly—"artificial trees," as somebody called them. Given how low the concentration of carbon dioxide in the air is, it seems obvious that the energy requirements for separating it out would be so high that the machines would be hopelessly uneconomic. But David Keith of the University of Calgary is one of the scientists who has shown that that is not necessarily so.

> I've ended up, along with several different groups around the world, working relatively seriously on the idea that we could build industrial equipment to pull carbon dioxide directly out of the air, [to] make concentrated streams of carbon dioxide. At first you might think that this is an absurdly hard thing to do, because the amount of carbon dioxide in the air is a half of a part per thousand, whereas the amount of carbon dioxide coming out of a power-plant exhaust is more like 10 or 15 percent, and we're having a lot of trouble and spending a lot of money to do that. But surprisingly, it's not necessarily that much harder when you look at the basic thermodynamics.
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> So there's been a fair amount of interest in this topic, and a guy called Klaus Lackner in the U.S. has been one of the leaders, and we're actually in the middle of patenting some technology that may produce competitive ways of doing this. We had this idea that the business model would be that you suck carbon dioxide out of the air, put it underground and people would pay you in carbon credits. But when you actually go talk to real businessmen, they say: We don't want to put this carbon dioxide underground. We want to make products with it.
>
> —David Keith, Canada research chair in energy and the environment, University of Calgary

Timing is everything. At this point in the interview, we were interrupted by a phone call from the university parking lot, where a semi-trailer had just arrived bearing the prototype of David Keith's machine. Where did he want it unloaded? So we went downstairs, and while he dealt with the logistics of the situation, I had a look at the machine, which took up much of the interior of the trailer. All I can tell you is that it was a rather convoluted hunk of metal, painted green, and looking vaguely as if it had been designed by Rube Goldberg. David Keith wouldn't tell me how it worked, because the patent is still pending, but he was quite happy to talk about how the economics of extracting carbon dioxide from the air might work:

> Let's say you are Richard Branson, and you run an airline, and you're worried that your airline will be shut down because of constraints on carbon dioxide. You know that you can't make electric airplanes or hydrogen-powered airplanes very well, and you think biofuels aren't going to work very well. One of the things you might want to do is sell truly carbon-neutral airplane seats, and air capture is a way to do that. Either by still burning petroleum in your airplane, but then sucking out an exact equal amount of carbon dioxide from the air and putting it underground in a certified way, so everybody agrees that you haven't added to the carbon dioxide in the air, *or* [by sucking] carbon dioxide out of the air and turn[ing] it into a fuel by adding energy—there's no free lunch here—and that might be far more cost-effective than doing hydrogen.
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> Let's say you have a source of hydrogen, which doesn't create carbon dioxide emissions, and you propose to use that to solve the global transportation problem. Forget where the hydrogen came from: could be solar power, nuclear power, not my problem right now. One option I have is the option we're all familiar with: that I put it in little hydrogen tanks in my car, and I run fuel cells and all that. There turns out to be immense problems with this, because hydrogen is a very low-density fuel with lots of problems . . .
>
> Another, quite different option is you take the hydrogen, you capture carbon dioxide out of the air, you mix

> the hydrogen and the carbon dioxide, which quite easily makes a fuel—you can make octane if you want to—and then you sell a carbon-neutral hydrocarbon. So you sell something that is compatible with the existing vehicle fleet of the world, but the carbon in the stuff you're selling—which is octane, just like gasoline—is stuff you got from the air. It's like returning the empty bottles after they've drunk it. So you're selling them this fuel, and they're burning it, putting carbon in the air, but then you're recapturing the same amount of carbon and selling it to them again. That's a business model that could conceivably take a whack at the global transportation market, which is the hardest part of the climate problem to crack.

The rival team, led by Klaus Lackner, a physicist at Columbia University, has some numbers to offer. They estimate that their machine (about the same size as Keith's) would initially cost about US$200,000 to build, though that would come down with high-volume production. It would be able to "scrub" about a tonne of carbon dioxide a day from the atmosphere (about the same amount that would be emitted to carry one passenger on a full plane from London to New York), so five or six hundred of the machines could compensate for the carbon dioxide emitted by one airliner, assuming that it crosses the Atlantic twice in a working day. Put that way, it sounds ludicrously uneconomic, but it may not be: if the only alternative was to stop flying, Richard Branson might be able to build the cost of buying and operating them into the ticket price without driving all the passengers away.

The question comes down to money, in the end. How much power, at what cost, does it take to scrub that tonne of carbon dioxide out of the air? If it is a cost per tonne that is lower than the going price of a carbon credit for one tonne (and you have somewhere to sequester the carbon dioxide), or if some manufacturer of fuel is willing to pay more for a tonne of carbon dioxide than it costs to extract, then this is a viable technology. Is it also an occasion of sin? Of course it is, but against the accusation of moral hazard, Lackner argues: "We are in a hurry to deal with climate change and will be very hard pressed to stop the train before we get to 450 ppm [parts per million]. This can help stop the train. I'd rather have a technology that allows us to use fossil fuels without destroying the planet, because people are going to use them anyway." (*Guardian* interview on May 29, 2008)

Could it be done on a scale that would make a really big dent in the rapid and accelerating accumulation of carbon dioxide in the atmosphere? That seems hard to believe, since the human race is now adding six gigatonnes a year to the load—but if the scrubbers performed as promised, it would only take twenty million of them to counter all that carbon dioxide. That's about three times the number of large trucks (more than two axles or more than four tires) in the United States: a big number, but not an unimaginable one. A harder question, as in the case of CCS technology, is what to do with all that carbon dioxide, as twenty years' worth of human carbon dioxide emissions, captured and liquefied, would fill Lake Michigan.

It is worth doing these back-of-an-envelope calculations about sulphates in the stratosphere, oceanic iron fertilisation, and "air capture" of carbon dioxide, even if the geo-engineering technologies under discussion are largely untested, because of the very serious possibility that all the conservation and mitigation measures that people around the planet take in the next twenty or thirty years will not be enough to stop global warming short of the point where the feedbacks are activated in a major way. "Some people say we can stop at 450 parts per million, but that's ludicrous," said Wallace Broecker, Lackner's chief scientific collaborator, in a recent interview published in the *Guardian*, May 24, 2008. "It will be hard, very hard, for us to stop at even 600 ppm. And if we carry on doing what we are doing now—very little—we are going to get up to 800 or 900 ppm."

Relatively slow-acting techniques for drawing carbon dioxide out of the atmosphere, if they prove to be environmentally sound and economically viable, could be deployed even before the world faces an imminent and grave climate crisis, in order to slow the arrival of that crisis or perhaps even avert it. Drastic measures for holding the temperature down by blocking solar radiation, on the other hand, should obviously not be deployed unless a grave crisis is actually upon us.

In the case of putting sulphur dioxide into the stratosphere, delaying until the last minute is cost-free because the cooling effect is relatively fast-acting. You would not wish to do that in anything but an extreme emergency in any case, as it could entail a substantial environmental cost. But there is another proposal for cutting solar radiation that involves intervention not in the stratosphere but about two hundred metres above sea level. It is the brainchild of John Latham, a British scientist who now works at the National Center for Atmospheric Research in Boulder, Colorado.

> The idea is to make clouds over the ocean reflect more sunlight than they do. I first started working on this idea in about 1990, but I think the stimulus for that came two decades before on a Welsh mountainside, looking out over the Irish Sea. My eight-year-old son Mike was with me, and we were looking at a beautiful sunset, and it was very shiny in patches. We were above the level of the clouds, and he asked me why they were so shiny. So I explained what was going on, and he laughed and he said "Clouds are soggy mirrors."
>
> There's a particular type of cloud, more extensive than any other clouds on Earth, called marine stratocumulus clouds. They're very low level, just a few hundred metres from the ocean's surface, they're very thin, just a few hundred metres thick, and they cover about a quarter of the oceanic surface. They reflect sunlight back to space—about 50 percent of the sunlight that lands on the top of those clouds is bounced back into space—so those

> clouds actually produce a very substantial amount of cooling naturally. But if we could rack up that percentage from about 50 to 55 percent, then we could produce a cooling that would be sufficient to compensate for the warming that results from a doubling of the carbon dioxide concentration in the atmosphere. So the idea is to make these clouds more reflective to incoming sunlight.

It isn't a perfect solution; nothing is. If you have lost the ice cover on the Arctic Ocean and the Earth's heat balance is sliding even further out of balance because the dark water is absorbing a lot more heat, perhaps you could compensate for that by seeding enough stratocumulus clouds with water droplets and reflecting an equivalent amount of sunlight. Unfortunately, you would not be cooling the part of the planet that most needs it, the Arctic, because the stratocumulus clouds are mostly found fairly close to the equator. You could end up with the worst of both worlds: huge disruptions to weather patterns in the equatorial regions, where you are making it cooler, while heating in the Arctic proceeds apace. You'd never choose to introduce such disruptions to the system voluntarily—but if the Arctic ice is already gone, maybe what you have to do to stop the Greenland ice cap from following suit is to concentrate on cooling the subtropical parts of the North Atlantic Current ("Gulf Stream"), which will later end up around Greenland. But don't cool it too much, or you might stop the whole current, which would give the Western Europeans a lot more cooling than they bargained for. Tricky business, this geo-engineering.

Latham's idea was partly chosen for its relatively low and controllable impact on the Earth climate system. He proposes fleets of unmanned, satellite-controlled vessels that spray tiny droplets of seawater into the air below the stratocumulus clouds. It doesn't take a lot of power: you just have to get the droplets a couple of metres up into the air, and updrafts will carry about half of them on up into the clouds a few hundred metres above. Once there, they increase the reflectivity of the cloud, which is determined mainly by the size of the droplets it contains. Smaller droplets are more reflective (because the same amount of water distributed among more and smaller droplets has a bigger surface area). Since the droplets that the ships spray would be considerably smaller than the average size of those that form naturally within the cloud, they would raise the reflectivity of the cloud by about 5 percent—and, as a bonus, clouds containing these smaller droplets tend to last longer before they disperse.

Stephen Salter, a professor of engineering design at Edinburgh University, has designed the wind-powered ships that would do the spraying. They would be relatively small—about forty metres in length and displacing only about two hundred tonnes, the size of a large ocean-going yacht—and could be mass-produced at a modest cost. They would have not conventional sails but Flettner rotors that generate thrust to move the ships forward by rotating in the wind (and also allow the ships to tack closer to the wind than fabric sails). The electrical power that rotates the cylinders and sprays the seawater into the air would be generated by very large propellers in the water that act as turbines, so the ships would need no fuel and could remain independent of land support for long periods of time.

> Everybody working in the field of climate recovery would prefer solutions to the global warming problem based on the use of non-carbon sources. But fourteen years after the Kyoto agreement was ready for signature, the rate of increase of atmospheric carbon dioxide has itself increased. It is therefore urgent to design and test all possible measures to stabilize temperature, for use if the present proposed methods are unsuccessful.
>
> It is technically possible to increase the reflectivity of marine stratocumulus clouds by spraying quite small quantities of sea water into the marine boundary layer

> . . . On reasonable assumptions of the present concentrations of condensation nuclei in mid-ocean air and drop life, the first global reduction of one watt per square metre will require spraying a total of only five cubic metres a second. Because of diminishing returns, the increase from 2.7 to 3.7 watts per square metre, needed to stabilize temperatures despite a future doubling of carbon dioxide levels, will require an extra thirty cubic metres of sea water a second.
>
> If necessary it would be possible to spray amounts sufficient to compensate for five watts per square metre over the entire earth surface. Operations in water en route to the Arctic will have secondary benefits in the restoration of ice cover and the reduction of methane release from Siberian permafrost. Operations may also be aimed at endangered coral.
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> —Stephen Salter and John Latham, "The Reversal of Global Warming by the Increase of the Albedo of Marine Stratocumulus Cloud," *The Engineer Online*

The fleets of spray vessels would be directed to stratocumulus-rich areas of the ocean by satellite commands, and migrate between the Northern and Southern hemispheres to follow the summer (the greater the solar radiation hitting the top of the clouds, the more efficient the process). They would avoid shipping lanes, anywhere with large numbers of icebergs, and sea areas that have land downwind that might suffer from altered rainfall as a result of their activities, but at least 80 percent of the world's oceans would be available for their operations.

Latham and Salter estimate that deploying fifty spray vessels with an expected service lifetime of twenty years and costing a few millions dollars each would be enough to compensate for one year's worth of global warming at the current rate of increase of carbon dioxide in the atmosphere. Deployment of a further fifty spray vessels each year could cancel out the heating due to that year's carbon dioxide emissions, so the annual investment would be relatively modest. If there should be unforeseen negative consequences of the technique, the spraying could be shut off at once, and conditions would revert to whatever the current "normal" is in a matter of days. And if the global climate should spin out of control, with rapid methane release or some other feedback kicking in sooner than expected, the number of vessels could be expanded rapidly to prevent a sharp rise in temperature.

It sounds almost too good to be true, and maybe it is. But it is sheer fecklessness to fail to investigate such possibilities aggressively, because we are currently conducting an unplanned experiment in global climate alteration through massive carbon dioxide release without any kind of safety net. It would be comforting to have at least one reserve position to fall back on, in case all those promises of future emissions cuts don't come true. You know, just like all the past promises of emissions cuts didn't come true. Three or four different tested and proven options for how to stop the temperature from soaring if the Kyoto process or its son or niece or second cousin doesn't deliver the goods in time would be even nicer.

Moral hazard be damned. This is serious.

CHAPTER EIGHT
Childhood's End

The larger the proportion of the Earth's biomass occupied by mankind and the animals and crops required to nourish us, the more involved we become in the transfer of solar and other energy throughout the entire system. As the transfer of power to our species proceeds, our responsibility for maintaining planetary homeostasis increases, whether we are conscious of the fact or not. Each time we significantly alter part of some natural process of regulation or introduce some new source of energy or information, we are increasing the probability that one of these changes will weaken the stability of the entire system . . . We shall have to tread carefully to avoid the cybernetic disasters of runaway positive feedback or of sustained oscillation . . .

This could happen if . . . man had encroached upon Gaia's functional powers to such an extent that he disabled her. He would then wake up one day to find that he had the permanent lifelong job of planetary maintenance engineer. Gaia would have retreated into the muds, and the ceaseless intricate task of keeping all the global cycles in balance would be ours. Then at last we should be riding that strange contraption, 'the spaceship Earth,' and whatever tamed and domesticated biosphere remained would indeed be our 'life support system' . . . Assuming the present per capita use of energy, we can guess that at less than 10,000 million [people] we should still be in a

> Gaian world. But somewhere beyond this figure, especially if the consumption of energy increases, lies the final choice of permanent enslavement on the prison hulk of the spaceship Earth, or gigadeath to enable the survivors to restore a Gaian world.
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> —James Lovelock,
> *Gaia: A New Look at Life on Earth*, 1979

Thirty years ago, when independent scientist James Lovelock wrote his seminal first book about what is now called "Earth System Science" in academic circles, but which he boldly named "Gaia," his concluding remarks about the fate of the "planetary maintenance engineer" struck me so forcibly that I have been able to quote them verbatim ever since. The world in which our species built its civilization used to seem such a stable, welcoming place, and maintained its stability so effortlessly and even invisibly, that nobody in the past would have dreamed of wishing to take up that thankless role, even if they could have imagined that human beings might one day acquire the knowledge and the power to take over the management of the Earth system. But we are now well on the way to acquiring those abilities, at least in a rudimentary form, and it begins to look probable that we will need some of them.

Birth rates have dropped sharply in the three decades since Lovelock wrote his first book. As a result, we are still well short of the ten billion people he set as the point at which our numbers might simply overwhelm the natural systems that regulate the global temperature, the chemical composition of the atmosphere, and other key elements in the equation and thereby succeed (most of the time) in keeping conditions on the planet suitable for abundant life. We may never hit ten billion, and the further short of that destination that we fall, the better it will be. But our energy consumption per capita has increased vastly beyond what anybody in the 1970s could have imagined—

nobody then foresaw the rapidly industrializing Asia of today—and the net effect is about the same. We are overwhelming the natural systems, and rapidly approaching the "runaway positive feedbacks" that concerned Lovelock even so long ago.

In 2007, the Intergovernmental Panel on Climate Change stated that global emissions of greenhouse gases must peak by 2015 if we are to have any chance of keeping the temperature rise to two degrees Celsius (and thus have a reasonable chance of not tripping the feedback mechanisms that could pitch us into runaway heating). In the same year, the International Energy Agency predicted that world energy use will grow 50 percent by 2030, and that fossil fuels will account for 77 percent of that increase. Only instant massive mobilization and wartime-style controls in every major industrialized and industrializing country could stop the rise in greenhouse-gas emissions by 2015, and you know that is not going to happen. So we are going to bust the boundaries. Indeed, the question that looms over us is the same one that comes from the back seat of the family car every ten minutes on long drives: "Are we there yet?" "There" being, in this case, the point at which we have to accept the job of planetary maintenance engineer, at least temporarily—and I think the answer is "Yes."

It was probably already too late to avoid inheriting the job even thirty years ago, although that was not clear at the time because we did not comprehend the sheer momentum of the industrial systems that we have built. It is almost certainly too late now. And maybe it is not altogether a bad thing that the most sentient form of life on the planet is beginning to acquire some ability to regulate the working of Gaia, in our own interests first of all, but potentially in the interests of the entire system.

This statement will stoke instant rage in those to whom rage comes easily, and cause dismay in many more who are appalled by what human civilization has done to the planet in less than ten thousand years. How dare anybody propose human beings as the stewards of the biosphere when their whole history shows that they are just a blight on the planet, devastating the land and emptying the sea of life? What the human race must do is leave everything that remains of the natural world alone to heal as best it can, and tread as lightly as we can upon the Earth. You can't trust us to intervene. Look at our track record.

Again, it's too late. That would have still been a viable course in 1800, but it isn't now. There are almost seven billion of us, and it is almost impossible to imagine a way that we can stop the growth before there are eight and a half billion. Our per capita energy use is immense, and it will continue to grow for at least two generations. The only way that our numbers could come down to a more "sustainable" total in less than several centuries is mass death through famine, war and disease. That may well happen, but I do not want it to: a great deal would be lost, and not just lives. Indeed, if the "wipeout" scenario has any relevance to our situation at all, then you definitely do not want high-technology human civilization to break down, because it provides us with the only set of tools that might enable us to avoid the very worst outcome of our current activities: a full-blown mass extinction.

Yes, of course: technically speaking, we have already initiated an extinction event simply by taking over so much of the planet's surface for our own purposes. The rate at which species are now disappearing is probably at least ten times higher than "normal," and maybe a hundred times higher. (More precise statements of the extinction rate are to be viewed with some suspicion, since nobody knows how many species there are.) But at the risk of sounding unsympathetic, I must point out that species come and go, and that 99 percent of those that ever lived were already extinct before human beings even evolved. For aesthetic reasons, we should stop decimating what is left of the large animal species that remain on the land and in the sea, but our most important priority is to preserve the species that perform vital functions in maintaining the biosphere (most of which are tiny and not in the least cuddly). That is a tricky business, in part because we don't always know which ones they are, but it is much more important than saving polar bears.

To the extent that the biosphere has operated without human intervention to maintain the recent climatic equilibrium—that is, the ten-thousand-year spell of warm and stable climate during which we have built our civilization—we should of course leave it alone to get on with the job. But we should be honest with ourselves: we are actually seeking to preserve one particular climatic state among many potential ones, ranging from deep glaciation to greenhouse extinction, because it suits our particular needs and tastes. We should also be realistic about what needs to be done. We have destabilized this highly desirable climatic equilibrium by our own inadvertent interventions in the past (two hundred years of burning fossil fuels), but given where we are now, it is highly unlikely that we can achieve the goal of restoring that equilibrium without further large and deliberate interventions in the system. We don't know enough yet about how the system works to do that safely, but that doesn't mean that we must never do it. It means that we must learn a lot more about the climate system, very fast, so that we *can* do it more safely.

> By failing to see that the Earth regulates its climate and composition, we have blundered into trying to do it ourselves, acting as if we were in charge. By doing this, we condemn ourselves to the worst form of slavery. If we choose to be the stewards of the Earth, then we are responsible for keeping the atmosphere, the ocean and the land surface right for life. A task we would soon find impossible . . .
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> To understand how impossible it is, think about how you would regulate your own temperature or the composition of your blood. Those with failing kidneys know the never-ending daily difficulty of adjusting water, salt and protein intake. The technological fix of dialysis helps, but is no replacement for living, healthy kidneys.
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> —James Lovelock, *The Independent*, January 16, 2006

I see Jim Lovelock as the most important figure in both the life sciences and the climate sciences for the past half-century. I suspect that in another hundred years, if enough from the present survives, he will be granted equal billing with Charles Darwin in the pantheon of scientific heroes. And here, in this quote from *The Independent*, he is saying that we must not do what I am recommending. To which I reply: if I have kidney disease, I definitely want dialysis. It might keep me alive long enough for a more permanent cure to be discovered, and at the least, it will give me more years with those I love.

Getting through the rest of this century without falling into the runaway global warming that Lovelock predicts is only likely if we do not breach the plus-2-degrees-Celsius boundary, and most climate scientists I have spoken to would feel a great deal easier if we never exceeded plus 1.5 degrees. Getting the concentration of carbon dioxide in the atmosphere back down to a relatively safe level—say, the 350 parts per million that James Hansen now advocates as a provisional target—would take even longer, for we passed that milestone some time in the 1980s. We can fully decarbonize our economies if we have enough time, but we are not going to achieve it on the schedule that is required if we are not to breach the boundary. We will pass 400 parts per million of carbon dioxide by 2013, we will probably hit 450 parts per million in the late 2020s, and it will be a miracle if we don't reach 500 parts per million before we can turn the tide.

We (and the biosphere in its current configuration) will only come through this crisis without huge losses if we can keep the temperature from going too high, despite what is happening in the short term to the carbon dioxide concentration in the atmosphere. We are going to get the miserable job of planetary maintenance engineer for a while, but the goal must be to work ourselves out of a job: to restore the natural systems that have done an excellent job of keeping the planet suitable for abundant life most of the time for the past several billion years. This is an emergency, however, and we have to intervene or all of Lovelock's predictions will come true.

What is being proposed is not intervention on a broad front. Nobody is suggesting that we take over the task of providing directly the ecosystem services that are now provided for free by ocean plankton, for example; rather, we should keep the sea surface temperature low enough for them to flourish. We don't know enough about the Earth system to do any fine tuning—but we probably do know how to keep the temperature below two degrees Celsius for the fifty or seventy-five years when we overrun the 450-parts-per-million boundary. If we don't, then we really are screwed.

But just keeping the temperature down artificially will not stop the oceans from becoming more and more acidic due to increased carbon dioxide, I hear a protester cry. No, it won't, but do you have some credible alternative that will stop acidification? Don't tell me "early and steep cuts in emissions," because I don't believe in the Climate Fairy. But we don't have to settle this debate right now. Let's wait five or ten years, and if those "early and steep cuts in emissions" still haven't happened, then we'll discuss it again. There's enough time for that.

In the meantime, though, I'd like lots of research to be done on geo-engineering techniques of all kinds, because I suspect that we will need them. A high level of carbon dioxide in the atmosphere has undesirable consequences that just keeping the temperature down cannot stop, but it would help a lot if we could keep the average global temperature low enough to avoid triggering large natural feedbacks that take the situation completely beyond our control. Keeping the temperature down could also prevent the kind of human catastrophes, including great wars, that would doom all our efforts to clear up the mess we have made.

The job, for the rest of this century, is repairing the damage we did over the past two centuries of industrialization to the homeostatic, Gaian systems that we didn't even realize we depended upon until relatively recently. That does not mean that we de-industrialize—this global society will live or die as a high-energy enterprise—but to begin with we must completely de-carbonize our energy, our transportation, and our industry. Then much of the forests that we cut down over the past two hundred years must be replanted, huge no-fishing reserves must be created to permit the repopulation of the oceans, and the amount of land we have removed from the natural cycles in order to grow food on it must fall from the current 40 percent of the Earth's land surface to 30 percent or less. It's not too late to fix most of the damage, if we have enough time and are not fatally distracted by catastrophes.

And how do we feed the eight-and-a-half billion people of the mid-century world—or nine billion, or nine-and-a half, take your pick—while we are reducing the amount of land under cultivation and cutting back on fishing? This is a high-tech civilization, and I suspect that the answer lies in that direction. Alberta, for example, produces more wheat and beef than any other Canadian province, but it is approaching the limit in terms of available water. So it is looking into non-traditional ways of producing those commodities.

> We really should be getting beyond growing the whole plant or the whole cow, when only certain parts are of primary value to us. If you think about wheat, it is primarily the kernel of wheat that is of primary importance to us . . . There are significant advances in molecular biology and in cell biology. In the medical field, we're really quite far advanced in growing artificial skin. You start with a small patch of human skin, and you grow a large patch. There's no real reason to think that that cannot be extended to other parts of the human body . . . and if that is so, it isn't all that far-fetched to think, well, why don't we just find ways of

> growing steak, or fish fillets, from a few cells by providing the appropriate nutrient medium?
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> What triggered this exploration in part was our discussion about water. In order to grow one kilogramme of beef, you require about thirteen thousand litres, thirteen thousand kilogrammes of water. The same is true for plants. Conceivably you can grow just the kernel, or just the starch that makes up the kernel, artificially . . . To grow a kilogramme of wheat flour takes about a thousand litres of water. If you want to visualize this as a milk carton of one litre, it takes about three bathtubs of water to produce that one milk carton of wheat flour. That's a very profligate way of using water, and with impending climate change, concerns about droughts, it's reasonable to try to explore other ways, not necessarily as replacements but as complements. And I think modern science is putting it within reach now . . .
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> It is not unnatural for a modern variant of an industry to have its roots in a traditional variant, so I could certainly foresee in the years to come that there will be farmers who could produce wheat or beef in both ways simultaneously, possibly for different markets.
>
> —Axel Meisen, chair of foresight,
> Alberta Research Council

Many people will simply be horrified by this proposal, and many others will suspect that the innocent little phrase, "possibly for different markets," foreshadows a two-tier world food system: real beef for the rich, vat-grown beef for the poor. Even if their taste and texture were exactly the same, considerations of prestige would produce that two-tier market. Still, it's a lot better than *Soylent Green*, and it could offer a way to uncouple human food production from the traditional farming techniques that have led us to alienate 40 percent of the world's land surface—and the most productive 40 percent, at that—from its proper task of contributing to the maintenance of the biosphere. We are going to see more proposals like this, and we are not going to be able to dismiss them out of hand.

Let us make the heroic assumption, just for a moment, that the human race will be clever enough to make it through this century without triggering runaway warming and a massive population dieback. Let us further assume that we have retained our high-technology civilization (for otherwise our chances of making it through unscathed would be very small), and that the experience has taught us something about the need to respect the natural systems that we depend upon. You may see these as low-probability assumptions, but you cannot deny that they are at least possible. What would that somewhat chastened end-of-the-century global society look like?

It would be a world with much greater equality of wealth between the old rich countries and the Majority World, because that is a precondition for making it through the crisis. Even with the most stringent population controls there would probably still be five or six billion of us, although there might be a gradual downward trend. Since most of those five or six billion would have access to the full industrialized lifestyle, enormous emphasis would have to be put on learning to "live lightly on the planet." Given the right technologies, it is not improbable that most people would still have personal transportation devices of some sort, that long-distance travel would continue to be possible for more than the privileged few, that those who wished to would still be eating meat (although, in many cases, ethically produced, vat-grown meat). This is not a wish-fulfilment dream; it is what we would probably get if we pass the test.

Various metaphors for our present situation come to mind, but the one that really sticks is the final exam. For more than ten thousand years, human beings have built a civilization that is now global in extent, but for most of that time we were really semi-barbaric children. Only two centuries ago, slavery was almost universal, women were an inferior caste almost everywhere, and war was the normal way of doing business. Resources were always scarce, so competition was usually a better strategy than cooperation. And, until the very end of that period, we had no real comprehension of the workings of the planet we lived on.

Then we began burning fossil fuels, and resources became abundant. Population and consumption both soared, of course, but so did science and knowledge. We began to understand our place in the universe, and that was very frightening. The nursery world that we thought we lived in, half playground, half battlefield, but unchanging and specially designed for human beings, turned out to be a fantasy. The real world was immensely old, it cared nothing for us, and there were many ways it could hurt us that we had never even imagined: ten-thousand-year volcanic cataclysms and hundred-metre sea level changes, ice ages and asteroid strikes, runaway greenhouse warming and supernovas a hundred light years away that could sterilize the planet. We realized we were on our own, and it was time to grow up.

We haven't done all that badly, really. We began by trying to behave better towards one another in our own societies—the great democratic revolutions, free universal education, the invention of the welfare state—and by the end of this two-century period we had even created semi-functional international institutions. Nobody would have put it this way at the time, but with hindsight you can see that we were actually building our capacity to take responsibility for people and events beyond our own horizons. Just as well, given what lies in wait for us. But it is worth remembering that all this only became possible because large numbers of people finally had the security and the leisure to think beyond the moment and to act for the future. We owe a lot to fossil fuels.

There was no alternative to burning fossil fuels in terms of getting an industrial, scientific civilization off the ground, because no other source of energy was available to a low-technology society. (And it was a one-time-only offer: we have used up all the easily accessible sources of fossil fuel, and any descendants of ours who are trying to restart an industrial civilization will be out of luck.) We went on burning coal and oil and gas heedlessly for almost two centuries, not suspecting that, in the long run, dependence on fossil fuels is a kind of suicide pact. And here is the little miracle that shows we still have more than our share of luck: at exactly the same time when it became clear that we have to stop burning fossil fuels, a wide variety of other technologies for generating energy became available. We are truly blessed.

So now we have to manage the transition, and we have about half a century to complete the job. Most of the changeover has got to come in the next twenty years, and we need to have completely decarbonized our economies by 2050. In the meantime, we have to keep the global average temperature from passing the plus-two-degrees-Celsius boundary no matter what the carbon dioxide concentration in the atmosphere is doing, and in the longer run we need to get the carbon dioxide down to 350 parts per million. That won't be easy, but it is the sort of task at which industrial societies excel.

We just barely scraped through the mid-term exam in the last century: we acquired the ability to destroy our civilization directly, by war, and we managed not to use it. Now it's the final exam, with the whole environment that our civilization depends on at stake. It's not just about knowledge and technical ability; it is also about self-restraint and the ability to cooperate. Grown-up values, if you like. How fortunate that we should be set such a test at a point in our history where we have at least some chance of passing it. And how interesting the long future that stretches out beyond it will be, if we do pass.