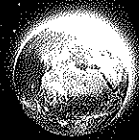


Clive Hamilton  
**Earthmasters**

THE DAWN OF THE AGE OF  
CLIMATE ENGINEERING

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**Earthmasters**



Yale

...ectively contemplate upping the ante on the same arrogant  
...reated the climate crisis, we could ask for no wiser nor more  
...uide than Clive Hamilton. A dazzling, multilayered exploration  
...the strange and terrifying world of geoengineering.

—NAOMI KLEIN, author of *The Shock Doctrine*

...han merely an excellent treatment of the pros and cons of  
...ering schemes aimed at slowing climate change, *Earthmasters*  
...e dawn of climate engineering as the perilous, ethically fraught  
...in our species' long drive to apply technology to control ever-  
...the planet. Hamilton's description of the powerful coalition of  
...ing's proponents – who they are and what motivates them – is  
...one of the strongest features of this remarkable book.

...STAVE SPETH, author of *Red Sky at Morning: America and the  
...Crisis of the Global Environment*

...on is one of the world's leading thinkers about the consequences  
...ustainability of our hyper-consumption and materialism. His  
...creasingly urgent, and in *Earthmasters* he clearly shows that we  
...ct megatechnological "solutions" to be problem-free when our  
...f how the biosphere works is so limited. The only thing we can  
...is ourselves, and we haven't done a very good job of that.

...D SUZUKI, author of *The Legacy: An Elder's Vision for Our  
...Sustainable Future*

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I would like to dedicate this book to Joe Romm of Climate Progress for his indefatigable, comprehensive and committed reporting on the science and politics of climate change.

# 1

## Why Geoengineering?

### Climate fix

As the effects of global warming begin to frighten us, geoengineering will come to dominate global politics. Scientists and engineers are now investigating methods to manipulate the Earth's cloud cover, change the oceans' chemical composition and blanket the planet with a layer of sunlight-reflecting particles. Geoengineering – deliberate, large-scale intervention in the climate system designed to counter global warming or offset some of its effects – is commonly divided into two broad classes. Carbon dioxide removal technologies aim to extract excess carbon dioxide from the atmosphere and store it somewhere less dangerous. This approach is a kind of clean-up operation after we have dumped our waste into the sky. Solar radiation management technologies seek to reduce the amount of sunlight reaching the planet, thereby reducing the amount of energy trapped in the atmosphere of 'greenhouse Earth'. This is not a clean-up but an attempt to mask one of the effects of dumping waste into the sky, a warming globe.

Diligent contributors to Wikipedia have listed some 45 proposed geoengineering schemes or variations on schemes. Eight or ten of them are receiving serious attention (and will be

considered in the next chapters). Some are grand in conception, some are prosaic; some are purely speculative, some are all too feasible; yet all of them tell us something interesting about how the Earth system works. Taken together they reveal a community of scientists who think about the planet on which we live in a way that is alien to the popular understanding. Let me give a few examples.

It is well known that as the sea-ice in the Arctic melts the Earth loses some of its albedo or reflectivity – white ice is replaced by dark seawater which absorbs more heat. If a large area of the Earth's surface could be whitened then more of the Sun's warmth would be reflected back into space rather than absorbed. A number of schemes have been proposed, including painting roofs white, which is unlikely to make any significant difference globally. What might be helpful would be to cut down all of the forests in Siberia and Canada. While it is generally believed that more forests are a good thing because trees absorb carbon, boreal (northern) forests have a downside. Compared to the snow-covered forest floor beneath, the trees are dark and absorb more solar radiation. If they were felled the exposed ground would reflect a significantly greater proportion of incoming solar radiation and the Earth would therefore be cooler. If such a suggestion appears outrageous it is in part because matters are never so simple in the Earth system. Warming would cause the snow on the denuded lands to melt, and the situation would be worse than before the forests were cleared.

More promisingly perhaps, at least at a local scale, is the attempt to rescue Peruvian glaciers, whose disappearance is depriving the adjacent grasslands and their livestock of their water supply. Painting the newly dark mountains with a white slurry of water, sand and lime keeps them cooler and allows ice to form; at least that is the hope.<sup>1</sup> The World Bank is funding research.

Another idea is to create a particle cloud between the Earth and the Sun from dust mined on the moon and scattered in the optimal place.<sup>2</sup> This is reminiscent of the US military's 'black cloud experiment' of 1973, which simulated the effect on the Earth's climate of reducing incoming solar radiation by a few per cent.<sup>3</sup> Consistent with the long history of military interest in climate control, the study was commissioned by the Defense Advanced Research Projects Agency, the Pentagon's technology research arm, and carried out by the RAND Corporation, the secretive think tank described as 'a key institutional building block of the Cold War American empire'.<sup>4</sup> I summon up the black cloud experiment here to flag the nascent military and strategic interest being stirred by geoengineering. As we will see in chapter 5, the attention of the RAND Corporation has recently returned to climate engineering.

In 1993 the esteemed journal *Climatic Change* published a novel scheme to counter global warming by the Indian physicist P. C. Jain.<sup>5</sup> Professor Jain began by reminding us that the amount of solar radiation reaching the Earth varies in inverse square to the distance of the Earth from the Sun. He therefore proposed that the effects of global warming could be countered by increasing the radius of the Earth's orbit around the Sun. An orbital expansion of 1–2 per cent would do it, although one of the side effects would be to add 5.5 days to each year. He then calculated how much energy would be needed to bring about such a shift in the Earth's celestial orbit. The answer is around  $10^{31}$  joules. How much is that? At the current annual rate of consumption, it is more than the amount of energy humans would consume over  $10^{20}$  years, or 100 billion billion years (the age of the universe is around 14 billion years). This seems like a lot, yet Professor Jain reminds us that 'in many areas of science, seemingly impossible things at one time have

become possible later'. Perhaps, he speculates, nuclear fusion will enable us to harness enough energy to expand the Earth's orbit. He nevertheless counsels caution: 'The whole galactic system is naturally and delicately balanced, and any tinkering with it can bring havoc by bringing alterations in orbits of other planets also.'<sup>6</sup>

The caution is well taken, although the intricate network of orbital dependence has stimulated another geoengineering suggestion. The thought is to send nuclear-armed rockets to the asteroid belt beyond the planets of our solar system so as to 'nudge' one or more into orbits that would pass closer to the Earth. Properly calibrated, the sling-shot effect from the asteroid's gravity would shift the Earth orbit out a bit.<sup>7</sup> Of course, if the calibration were a little out, the planet could be sent careening off into a cold, dark universe, or suffer a drastic planet-scale freezing from the dust thrown up by an asteroid strike.

Some of these schemes seem properly to belong in an H. G. Wells novel or a geeks' discussion group, and too much emphasis on them for the delights of ridicule would give a very unbalanced impression of the research programme into climate engineering now underway. That imbalance will be rectified in the next chapters where we will see that serious work is being conducted on schemes to regulate the Earth system by changing the chemical composition of the world's oceans, modifying the layer of clouds that covers a large portion of the oceans and installing a 'solar shield', a layer of sulphate particles in the upper atmosphere to reduce the amount of sunlight reaching the planet. There are some who believe that we will have no choice but to resort to these radical interventions. How did we get to this point? The simple answer is that the scientists who understand climate change most deeply have become afraid.

### Hope against fear

In 1959 David E. Price, MD, US Assistant Surgeon General, addressed a conference of industrial hygienists with these words:

we live under the shadow of a haunting fear that something may corrupt the environment to the point where man joins the dinosaurs as an obsolete form of life. And what makes these thoughts all the more disturbing is the knowledge that our fate could perhaps be sealed 20 or more years before the development of symptoms.<sup>8</sup>

The shadow under which Americans lived was the dual fear of atomic radiation and chemical pollution. Trepidation that the air might be unsafe to breathe gripped the nation. It was the not-knowing that gave rise to a 'mass investment in worry' unmatched, said Price, by an investment in efforts to find out. All that was to change within a few years, spurred by Rachel Carson's earth-shaking book *Silent Spring*, published in 1962, which both confirmed American anxieties about the impact of the chemical war in agriculture and triggered the rise of modern environmentalism.

The haunting fear that something is corrupting the environment has returned, at least for some. Within our breasts fear and hope are duelling. For a few, the reasons to be afraid have prevailed; for most, hope fights on valiantly. Yet hope wages a losing battle; as the scientists each month publish more reasons to worry, and the lethargy of political leaders drains the wellsprings of hope. In 1959 Dr Price invoked that all-conquering sentiment of American greatness, unbounded optimism: 'Stronger than fear is the conviction that what may at times appear to be the shadow of extinction is in reality the darkness preceding the dawn of the greatest era of

progress man has ever known.<sup>9</sup> He was right about the post-war decades. But the world has changed, and now there is a constant trickle of defectors, traitors to hope. To pick out one, the chair of the International Risk Governance Council, Donald Johnston, for ten years the secretary-general of the Organisation for Economic Co-operation and Development (OECD), recently wrote: 'By nature I am not a pessimist, but it requires more optimism than I can generate to believe' that the world will limit warming to 2°C higher than the pre-industrial level.<sup>10</sup> Business as usual is a more likely scenario, he added, taking the concentration of carbon dioxide in the atmosphere from its pre-industrial level of 280 parts per million past its current 395 ppm to 700 ppm this century, 'with horrendous climate change and unthinkable economic and societal consequences'.

The anxiety deepened each year through the 2000s as it became clearer that the range of emissions paths mapped out by experts in the 1990s were unduly optimistic and that the actual growth in emissions, boosted by explosive growth in China, has described a pathway that is worse than the worst-case scenario. When scientists announced that the growth of global greenhouse gas emissions in 2010 was almost 6 per cent, breaking all previous records and wiping out the benefits of a temporary lull due to the global recession, many climate scientists around the world drew a sharp in-breath.

The International Energy Agency of the OECD is a staid organization that for years has shared the worldview of oil and coal industry executives. It is the last international body that could be accused of green sympathies, other than the Organization of Petroleum Exporting Countries. So a frisson of dread ran through the climate change community in November 2011 when the IEA released its annual *World Energy Outlook*, the 'bible' of the energy

sector. It exposed the target of keeping warming below the 'dangerous' level of 2°C as a pipe-dream; on current projections, the energy infrastructure expected to be in place as early as 2017 will be enough to lock in future carbon emissions that will warm the Earth by much more. Coal-fired power plants have a lifetime of 50 or 60 years. Waiting for new energy technologies is not an option. If governments do no more than implement the policies they are currently committed to, the IEA expects the world to warm by 3.5°C by the end of the century. 'On planned policies, rising fossil energy use will lead to irreversible and potentially catastrophic climate change.'<sup>11</sup> If those policy goals prove to be more aspirational than actual then the world is on track for average warming of 6°C above pre-industrial levels, which is almost unthinkable.

It's hard to communicate to the public what a world warmed by 3.5°C will be like, let alone 6°C, or even that the IEA, and all the other organizations saying the same thing, should be taken seriously.<sup>12</sup> After all, for many people one unseasonable snowstorm is enough to nullify decades of painstaking scientific study. And psychologists have discovered that, after accounting for all other factors, when people are put in a room and asked about climate change they are significantly more likely to agree that global warming is 'a proven fact' if the thermostat is turned up.<sup>13</sup> Patients with diseases they believe to be serious but untreatable are markedly less likely to agree to diagnostic tests.<sup>14</sup> If it's bad, I don't want to know. Suffice it to say here that 3.5°C means a different kind of world, one hotter than it has been for 15 million years, and not the kind of world on which modern life forms evolved. It would be, eventually, a world without ice – no glaciers, no Arctic sea-ice, no Greenland ice sheet and, almost inconceivably, no Antarctic ice mass. The destabilization of the Earth's climate and natural systems

expected this century under the IEA's more 'optimistic' scenario would cascade through the centuries beyond.

For at least a decade, climate scientists and environmental groups have been disturbed by the widening gap between the actions demanded by the evidence and those being implemented or even considered by the major emitting nations. A creeping fear took hold that the truth would be faced too late. After the 1997 Kyoto agreement to reduce global emissions there was an expectation that, having recognized the danger, the world would respond with policies to turn the curve of global emissions downwards. Despite the almost immediate repudiation of the protocol by the United States and Australia it was possible to retain the hope that good sense would prevail. Yet the attacks on the protocol were so persistent and effective that even today journalists unthinkingly reproduce talking points of climate change deniers such as that 'China refused to sign' the treaty. (In fact, China ratified the protocol in August 2002.)

By 2005 the Kyoto Protocol had been ratified by enough nations for it to enter into force. Yet by then it seemed like a pyrrhic victory, its inadequacy highlighted by the fact that growth in world emissions, far from turning down or even stabilizing, had actually accelerated. In the 1970s and 1980s global emissions of carbon dioxide from burning fossil fuels grew at 2 per cent each year. In the 1990s they had fallen to 1 per cent, giving some grounds for cheer. However, from the year 2000, driven mostly by China's astonishing economic expansion, the growth rate of the world's carbon dioxide emissions almost trebled to 3 per cent each year.<sup>15</sup> For those who grasped the enormity of what was at stake, the remnant forces of hope for international action were gathered together for one last mighty push at the Copenhagen conference in 2009. The collapse of the talks left an abyss of despair for the future of the world, one

that was not papered over by the milquetoast agreement in Durban in 2011 to begin negotiations for a treaty, to be agreed in 2015, to take effect not before 2020. It is as if the ostriches had awarded themselves another decade to bury their heads. As philosopher René Girard asked: What do we make of today's political leaders 'who claim to be saving us when in fact they are plunging us deeper into devastation each day?'<sup>16</sup>

While governments have been dragging their feet on abatement measures, there has been no shortage of enthusiasm to open up new sources of fossil energy. The Canadian government has facilitated the development of that country's vast tar sands, the most environmentally destructive source of oil. The Russian government, after sending a submarine to plant a flag on the floor of the ice-depleted Arctic sea, encourages its firms to drill for oil, while other oil companies circle. To fend off peak oil (the point after which petroleum production goes into decline because oil fields are being depleted and no new ones can be found), governments in China, South Africa, India and Australia are backing companies that want to revive processes that convert coal into oil. Each of these is worse for the environment than existing sources of fossil fuels, yet they present lucrative commercial opportunities and attract official backing. After pointing out that the amount of carbon in the world's proven coal, oil and gas reserves is five times greater than the amount scientists say it is safe to put into the atmosphere, Bill McKibben notes the irony of US Secretary of State Hillary Clinton travelling to the Arctic to see the damage caused by warming – 'sobering', she called it – before getting down to negotiations with other foreign ministers about how to get access to the new Arctic oil reserves.<sup>17</sup> In this schizoid world, perhaps no nation can compete with Australia. While a modest price was introduced on carbon emissions in 2012, the expansion of new mines to augment the

nation's coal exports, already the largest in the world, proceeds apace. According to one estimate, over the next decade the impact on global greenhouse gas emissions of the expansion of Australian coal exports will be 11 times greater than the reduction due to the carbon price legislation.<sup>18</sup>

At the same time, science has come under attack from a well-organized and increasingly vociferous campaign of denial. We will see the contours of this campaign later in the book, but it has taken the form of a flat-out rejection of climate science. News outlets, especially conservative ones, have given prominence to a handful of apparently qualified people who claim to be able to disprove all of the main propositions of climate science. These 'sceptics' have not been able to come up with any evidence for their claims and so they cannot be found in the scientific journals; but that has not dented their appeal to large numbers of lay people, newspaper columnists and political leaders who are looking for a reason, any reason, to reject the vast accumulation of evidence from a range of sources showing that we are in deep trouble.

In a question and answer session following a public lecture, the prominent (and genuinely sceptical) climate scientist Chris Rapley was vociferously challenged by a climate denier in the audience. (The individual's wife fled the lecture theatre as he rose to speak!) After responding calmly to a torrent of accusations, to no effect, Rapley stopped and asked his accuser what it would take to convince him that he was wrong, that climate change is real, dangerous and caused by humans. His critic ignored the question and it was clear to the audience that no amount of evidence could change his mind. A fair-minded man, Rapley later posed the same question to himself. He answered that he would change his mind in response to a research paper, published in a peer-reviewed journal, revealing a feedback effect that neutralized climate change, along with an

explanation as to why it had remained undetected or latent until now. The new evidence would require confirmation from an expert in the field whom he holds in esteem.<sup>19</sup>

A sceptic is one who carefully filters received knowledge to see which propositions stand up to independent scrutiny. But one thing we immediately notice about the contributions of climate 'sceptics' is the absence of a quizzical, thoughtful approach. Among those who debate the science of climate change they are the ones who profess to be most *certain*, insisting vehemently on the falsity of the claims of climate scientists and convinced of the correctness of their own opinions. The true sceptics are, of course, to be found among climate scientists themselves. As a matter of cultural practice and professional rivalry, research scientists routinely subject the work of their peers to the most critical scrutiny. It is a mark of quiet professional pride to find mistakes in the work of one's fellow researchers. If the Intergovernmental Panel on Climate Change (IPCC) of the United Nations can be accused of anything, it is of an excess of caution in reporting the science.

### Feedback science

While climate scientists observed these baleful political developments, their work provided additional grounds for disquiet. Building on the discoveries of palaeoclimatologists and more advanced knowledge of the functioning of the Earth system, they began to focus on the dangers of feedback effects in the climate system, that is, responses in the Earth system that amplify or dampen the direct effects on warming of rising greenhouse gas emissions. For example, as warming melts the Arctic ice cap (which coats the Arctic Sea) the exposed water is darker than the highly reflective ice it replaces and absorbs more heat from the

Sun. 'Arctic amplification' has seen the rate of warming in the Arctic occur at two to four times the global average.<sup>20</sup> Many in the expert community were shocked by the dramatic declines in Arctic summer sea-ice in 2005 and especially 2007. Warmer Arctic waters are causing complex changes to climate patterns in the northern zones, including melting of permafrost (now a misnomer). The release of frozen methane, a highly potent greenhouse gas, is expected to further amplify warming.

There are negative feedback effects that dampen warming and tend to return the climate system towards an equilibrium state – for example, over very long timescales enhanced chemical weathering of rocks may see more carbon dioxide taken out of the atmosphere and stored in the deep ocean – but overall the destabilizing effects are expected to be much more powerful.<sup>21</sup> Since the early 2000s research into feedback effects has gathered pace, not least because understanding these processes is essential to filling the gaps between the climate models and the actual behaviour of the climate system.

The study of feedbacks has been closely related to another emerging idea – that of tipping points. For example, when warming in Siberia reaches a certain threshold the frozen ground will thaw, releasing methane into the atmosphere. The Earth's climate is a 'non-linear' system, that is, changes in one variable do not lead to simple proportional changes in related ones. The equations are far more complex. In non-linear systems, a small change in one state may initially have only small effects but at some point a threshold may be crossed where the system, driven by amplifying feedbacks, flips suddenly into a new state. Research emerging from palaeoclimatologists has fed these concerns. They have discovered many instances in the Earth's climate record of the climate shifting abruptly from one state to another within a few decades. The

esteemed palaeoclimatologist Wally Broecker highlighted this fact when in 1995 he wrote: 'The palaeoclimate record shouts out to us that, far from being self-stabilizing, the Earth's climate system is an ornery beast which overreacts even to small nudges.'<sup>22</sup>

The existence of tipping points destroys the comforting idea that the slow build-up of greenhouse gases is causing a gradual change in temperature and that when it gets bad enough we can do something about it. The essential belief on which global negotiations were founded was increasingly seen to be dangerously wrong. The emerging science of abrupt climate change was reviewed in a landmark report, published in 2002 by the US National Research Council.<sup>23</sup> One of the authors, the director of the Woods Hole Oceanographic Institution, noted 'recent and rapidly advancing evidence that Earth's climate repeatedly has shifted abruptly and dramatically in the past, and is capable of doing so in the future.' Dr Robert Gagosian went on:

This new paradigm of abrupt climate change has been well established over the last decade by research of ocean, earth and atmosphere scientists at many institutions worldwide. But the concept remains little known and scarcely appreciated in the wider community of scientists, economists, policy makers, and world political and business leaders. Thus, world leaders may be planning for climate scenarios of global warming that are opposite to what might actually occur.<sup>24</sup>

The idea was born that within the next few decades we may face a 'climate emergency'. Palaeoclimatologists explained that although the Earth's climate has always been in a state of flux, shifts may be so sudden that natural systems, such as forest ecosystems, are unable to adapt and thus disappear. Abrupt climate change in the



past is thought to explain some mass extinctions. In 2009 a group of eminent Earth scientists summarized their growing concerns about feedback effects, tipping points and abrupt climate change in an article in *Nature*. Current climate models, they wrote:

do not include long-term reinforcing feedback processes that further warm the climate, such as decreases in the surface area of ice cover or changes in the distribution of vegetation. If these slow feedbacks are included, doubling CO<sub>2</sub> levels gives an eventual temperature increase of 6°C (with a probable uncertainty range of 4–8°C). This would threaten the ecological life-support systems that have developed in the late Quaternary environment [the last half to one million years], and would severely challenge the viability of contemporary human societies.<sup>25</sup>

### The floodgates

In the face of ever-increasing global greenhouse gas emissions, political inertia and worries about sudden climate change, some scientists began to mull over what could be done to slow the world's apparently unstoppable rush into the abyss. Among themselves they began to talk about possible responses to a climate emergency, such as a massive methane release following accelerated melting of permafrost, the collapse of the West Antarctic ice sheet, or rapid disappearance of the Amazon forests due to heat-stress and drought. Any of these could quickly shift the global climate into a new state, and there would be no way of recovering the situation. How could we intervene to prevent these things happening? If Plan A, persuading the world to cut emissions, is failing, shouldn't we have a Plan B? The search for an alternative to emission cuts led to the idea of engineering the climate.

In the 1990s proposals for geoengineering were regarded by the mainstream as fanciful and a distraction from the real task of reducing emissions. Although Plan B had been a topic of private speculation for some years, almost all climate scientists took the view that the availability of an alternative to cutting emissions, even if manifestly inferior, would prove so alluring to political leaders that it would further undermine the will to do what must be done. To canvass climate engineering, let alone advocate it, would be unethical. But the longer political leaders prevaricated the louder the silence surrounding geoengineering became. The frustration became too much for Paul Crutzen, the eminent Dutch atmospheric scientist who had shared the Nobel Prize for discovering the key chemical reactions needed to explain the hole in the ozone layer. So he penned an editorial essay, 'Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?', published in the journal *Climatic Change* in 2006.<sup>26</sup> His intervention broke the taboo on geoengineering.

Expecting the political process to respond adequately to the imperative to cut emissions, Crutzen argued, had become a 'pious wish'. It would be prudent to invest in a substantial research programme to test the feasibility of cooling the Earth by injecting sulphate aerosols into the upper atmosphere in order to reflect a greater portion of sunlight back into space. Crutzen expressed particular concern at the 'Catch-22' presented by the fact that governments in developing countries are following industrialized countries with measures to clean up urban air pollution from cars, factories and power plants, responsible, he wrote, for some 500,000 premature deaths each year. That pollution, especially the high sulphur emissions over much of East Asia, is helping to cool the planet; cleaning up the air would, over a brief decade, lead to an unprecedented increase in global temperature by almost 1°C over

land, and 4°C in the Arctic. Without an 'escape route against strongly increasing temperatures', he wrote, continued emissions growth combined with anti-pollution laws would bring about potentially catastrophic effects on ecosystems. Noting that the development of the Antarctic ozone hole was 'sudden and unpredicted', Crutzen wanted to alert the world to the risks of unexpected warming.

Many of Crutzen's colleagues at the Max Planck Institute and elsewhere reacted angrily to his intervention. In anticipation, one of his associates, Mark Lawrence, wrote a paper in his defence titled 'The geoengineering dilemma: To speak or not to speak?'. Lawrence referred to the 'passionate outcry by several prominent scientists claiming that it is irresponsible to publish' calls for research into geoengineering, and provided several counter-arguments for why it was time to break the taboo.<sup>27</sup> Nevertheless, the ferocity of the response shocked Crutzen. He weathered the storm and time presently proved that if he had not intervened someone else would have soon enough; the pressure had become irresistible.

By early 2009, three years after Paul Crutzen opened the flood-gates, more than half of leading scientists who responded to a poll by the *Independent* newspaper agreed that 'the situation is now so dire that we need a backup plan.'<sup>28</sup> That was before the Copenhagen fiasco. A third disagreed with the proposition, not because they assessed the situation differently but because they believed the better response is to commit more strongly to Plan A. The Copenhagen conference in December 2009 was the first of the annual international climate change jamborees at which geoengineering proposals had a significant presence at various side events.<sup>29</sup> A year later the IPCC decided for the first time to incorporate into its next report an evaluation of geoengineering as a response to global warming.

Research into various schemes to engineer the climate has been accelerating rapidly. A network of scientists, entrepreneurs and advocates has formed and is gaining influence in the scientific community and in government. According to one observer, John Vidal:

From just a few individuals working in the field 20 years ago, today there are hundreds of groups and institutions proposing experiments. . . . The range of techno-fixes is growing by the month . . . Most are unlikely to be considered seriously but some are being pushed hard by entrepreneurs and businessmen attracted by the potential to make billions of dollars in an emerging system of UN global carbon credits.<sup>30</sup>

When this was written in 2011, I think the first claim was something of an overstatement, although it will be true soon enough. While the number of researchers expressing interest in the area has grown substantially, and entrepreneurs and scientists are registering patents for various techniques, the international debate over geoengineering and its governance remains dominated by a very small group of experts, mostly scientists but including a handful of economists, lawyers and policy experts. In 2009 some members of that small group could write: 'Nearly the entire community of geoengineering scientists could fit comfortably in a single university seminar room, and the entire scientific literature on the subject could be read during the course of a transatlantic flight.'<sup>31</sup> That was an exaggeration then and is certainly untrue now as the scientific literature has ballooned.

That someone of Paul Crutzen's stature and 'undoubted commitment to protecting the natural world – he was described in *Time* magazine as 'the chief scientific caretaker of life on the

planet<sup>32</sup> – should call for serious research into geoengineering as a response to global warming must give pause for thought. Geoengineering presents a profound dilemma, not just for climate scientists, but also for environmentalists. It is a dilemma that all citizens will soon need to face. Many find repellent the idea, embodied in some geoengineering schemes, of attempting to take control of the Earth's climate as a whole. It is, surely, the ultimate expression of humankind's technological arrogance. Yet if the alternative is to stand back and watch humanity plunge the Earth into an era of irreversible and hostile climate change, what is one to do?

Perhaps Crutzen's only offence was to arrive at the conclusion a decade ahead of most others. On the other hand, his well-meaning intervention might legitimize the stance of hitherto fringe voices whose motives are less politically pure or sympathetic to environmental protection. That was his colleagues' fear, and it was a reasonable one. As we will see, climate engineering is intuitively appealing to a powerful strand of Western technological thinking and conservative politicking that sees no ethical or other obstacle to total domination of the planet. It is a Promethean urge named after the Greek titan who gave to humans the tools of technological mastery. Promethean plans have always met resistance from those who share a deep mistrust of human technological overreach, those who heed the warning that Nemesis waits in the shadows to punish Hubris. If Prometheus is the god of technological mastery, who is the Greek divinity of caution? Perhaps the closest is Soteria, the goddess of safety, preservation and deliverance from harm.<sup>33</sup> I will suggest that climate engineering is the last battle in a titanic struggle between Prometheans and Soterians, with the prize nothing less than the survival of the world we know now.

As will become apparent, one cannot assume a simple correspondence between Promethean and Soterian sympathies and

support for and opposition to geoengineering. Paul Crutzen, for example, is a Soterian. As will become apparent, I have serious doubts about the wisdom of any attempt by humans to take control of the weather. The reasons will become plain, but at their heart is a conviction that the Earth is unlikely to collaborate in our plans, and we should heed the kind of warning most famously expressed by Robert Burns:

The best laid schemes of Mice and Men  
oft go awry,  
And leave us nothing but grief and pain,  
For promised joy!

I hope to explain, not least by drawing on Earth system science, an understanding of the Earth that inclines to this conviction.

Yet if I am not *for* geoengineering then that means I must accept climate disruption, doesn't it? If most of the world continues to entertain the fantasy that global warming is trivial or a long way off, or that governments will respond in time to avoid climate chaos, and if Crutzen and a few others, despairing at this blindness, want to be ready to intervene radically when the world comes to its senses and realizes cutting emissions will come too late, where does that leave me politically and philosophically? Answering that question is a work in progress, one I hope will be resolved by the time I reach the last chapter of this book.