Chapter 19
DECARBONIZATION IN THE ANTHROPOCENE

SYNOPSIS

I. WELCOME TO THE ANTHROPOCENE

For the last 10,000 years, we have been living in the Holocene, a relatively stable, interglacial period that has allowed agriculture and complex societies to develop and flourish. Today, however, humans are the dominant driver of change not only to Earth itself but also to Earth's processes; we are changing the way the Earth works. In other words, humans "have become a force of nature reshaping the planet on a geological scale — but at a far-faster-than-geological speed." *Welcome to the Anthropocene***,** THE ECONOMIST, May 26, 2011. Human impact is now so profound that some scientists now argue we have departed the Holocene for a new epoch, the Anthropocene: the age of man. Paul J. Crutzen & Eugene F. Stoermer, *The "Anthropocene*,*"* GLOBAL CHANGE NEWSLETTER, vol. 41, May 2000, at 17.

As Paul Crutzen and Eugene Stoermer write, beginning with the invention of the steam engine in 1784 by James Watt and the start of the industrial revolution, the expansion of the human population and its exploitation of Earth's resources have been astounding:

- In the past 300 years, the human population has increased more than tenfold to more than 7 billion;
- The growth in the human population has been accompanied by increased cattle production to more than 1.4 billion;

- Human action has transformed 30 to 50 percent of the land surface;
- The release of about 160 teragrams per year of sulfur dioxide (SO_2) globally to the atmosphere by coal and oil burning is at least two times larger than the sum of all natural emissions, which occurs mainly as marine dimethyl-sulfide from the oceans;
- More nitrogen is now fixed synthetically and applied as fertilizers in agriculture than is fixed naturally in all terrestrial ecosystems;
- Human activity has increased the species extinction rate by one thousand to ten thousand fold in the tropical rain forests; and
- Humans consume more than half of all accessible fresh water.

Id. Human activities have also greatly affected Earth's climate systems, another reason why some scientists have begun calling this epoch the Anthropocene. As discussed in Chapter 1, emissions of carbon dioxide (CO_2) have increased by more than 30 percent and methane (CH_4) by more than 100 percent. Due to anthropogenic CO_2 emissions, atmospheric CO_2 concentrations now exceed 400 parts per million (ppm), and we are on a trajectory to increase global average temperatures by more than 3°C above preindustrial levels. The rise in atmospheric concentrations of greenhouse gases (GHGs) may cause Earth's climate to depart significantly from natural behavior for more than the next 50,000 years.

Barring some catastrophic natural calamity, such as an unexpected epidemic, a large-scale nuclear war, an asteroid impact, or a new ice age, humankind will continue to exert a powerful geological force for millennia. However, the Anthropocene does not inevitably lead us to the post-apocalyptic future portrayed in *Mad Max*, in which desperate survivors fight savagely for fuel. An important element of the Anthropocene that must be kept in mind is that we have reached this new epoch due to choices we have made as a collection of societies and a global society.

Thus, while labeling this epoch the Anthropocene forces us to confront the challenge impressed upon us by our past choices, it also encourages us to make deliberate choices for ameliorating the effects of the Anthropocene: "An exciting, but also difficult and daunting task lies ahead of the global research and engineering community to guide mankind towards global, sustainable, environmental management." Crutzen & Stoermer, at 18. Or as *The Economist* puts it: "The challenge of the Anthropocene is to use human ingenuity to set things up so that the planet can accomplish its 21st-century task." *Welcome to the Anthropocene*, THE ECONOMIST, May 26, 2011.

That task, as many see it, is to stabilize atmospheric GHG concentrations at 350 ppm or to hold the average global temperature to no more than 2°C above pre-industrial levels. But how to get there is uncertain. With CO_2 concentrations already approaching 400 ppm and CO_2 emissions expected to remain high for many years, particularly in developing countries to help meet basic human needs, how do we return to 350 ppm?

This chapter explores some of the ideas for doing so. For many, the future requires countries, particularly developed countries, to go carbon free or even carbon negative. If so, how do we encourage the kind of technological transformation necessary to revolutionize our energy system? For others, the urgency of climate change, as we potentially near tipping points such as the release of large amounts of CO_2 and methane from a thawing permafrost or massive sea-level rise from melting icecaps, demands a future that includes geoengineering — large-scale intentional interventions to counteract climate change. Have we reached the point where the large-scale, intentional manipulation of the atmosphere represents a precautionary approach?

II. THE CHALLENGE AHEAD

As discussed in Chapter 1, the relationship between human emissions of greenhouse gases and on-the-ground impacts necessitates taking action to transform our economy. At the time of the last IPCC report in 2007, the atmospheric concentration of CO_2 had reached 382 parts per million. UNITED NATIONS ENVIRONMENT PROGRAM, BRIDGING THE EMISSIONS GAP: A UNEP SYNTHESIS REPORT 9 (2011). By March 2013, the global atmospheric concentration of CO_2 had exceeded 397 ppm. When other GHGs are added to the mix, concentrations have been above 450ppm CO_2 equivalent (CO_2eq) since 2003. Katy Human, *NOAA: Carbon Dioxide Levels Reach Milestone at Arctic Sites* (NOAA, May 13, 2012). Many scientists argue that CO_2 concentrations above 350 ppm and CO_2eq concentrations above 500 ppm must be avoided to achieve the current goal of the climate change regime to keep temperature from increasing 2°C above pre-industrial levels. Emission trajectories consistent with a "likely" (greater than 66 percent) chance of meeting the 2°C target must peak before 2020 and have emission levels in 2020 around 44 gigatons CO_2eq (GtCO_2eq), with global emissions declining steeply thereafter — on average 2.6 percent per year. As part of the climate change regime, 86 countries have made pledges to reduce emissions, but these pledges, at best, are 6 GtCO_2eq short of meeting that goal. In fact, the gap between pledges and the 2°C goal are certain to be much higher because many of the pledges are conditional and the United States is not likely to meet its pledge of reducing its 2005 emissions by 17 percent by 2020. UNITED NATIONS ENVIRONMENT PROGRAM, BRIDGING THE EMISSIONS GAP: A UNEP SYNTHESIS REPORT 9 (2011).

Meeting the 2°C goal will clearly be challenging. As Professor Howard Latin reminds us,

> [o]vercoming global climate change will probably be the most difficult, expensive, complicated, controversial task the human race has ever undertaken on a collective basis, and there is certainly no guarantee that we will succeed in meeting this responsibility to the Earth and to future generations of human beings. Successful climate change policies must accomplish two demanding goals concurrently: eliminating as much residual GHG pollution as feasible to stabilize and then reduce the atmospheric GHG concentration that causes the greenhouse effect, and promoting greater economic and social welfare in developing countries

> that otherwise will continue discharging more GHGs into the atmosphere every year.

HOWARD A. LATIN, CLIMATE CHANGE POLICY FAILURES 151 (2012).

Technology will certainly play a fundamental role in whether we succeed in meeting the challenge; technology imposes some constraints that add to the challenge of meeting the 2°C goal but it also provides the means by which we will meet the goal. The International Energy Agency (IEA) has recently described some of the challenges our current energy infrastructure imposes on us. In the IEA's "450 Scenario," strong policy actions are taken to peak global energy-related CO_2 emissions before 2020 with those emissions declining to 21.6 Gt by 2035. IEA assumes that this scenario has a 50 percent probability of limiting the average global temperature increase to 2°C by keeping total GHG concentrations to 450 ppm CO_2eq. However, the 450 Scenario requires investment in and consumer spending on energy-related equipment totaling $15.2 trillion relative to an emissions pathway that takes us to a long-term rise in the average global temperature in excess of 3.5°C. IEA's analysis includes the following caution:

> **The long economic lifetimes of much of the world's energy-related capital stock mean that there is little scope for delaying action to move onto the 450 emissions trajectory without having to retire some stock early.** We calculate that 80% of the cumulative CO_2 emitted worldwide between 2009 and 2035 in the 450 Scenario is already "locked-in" by capital stock — including power stations, buildings and factories — that either exists now or is under construction and will still be operational by 2035, leaving little additional room for manoeuvre. If internationally co-ordinated action is not taken by 2017, we project that all permissible emissions in the 450 Scenario would come from the infrastructure then existing, so that all new infrastructure from then until 2035 would need to be zero-carbon, unless emitting infrastructure is retired before the end of its economic lifetime to make headroom for new investment. This would theoretically be possible at very high cost, but is probably not practicable politically.
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> **The long lifetime of capital stock in the power sector means that the sector accounts for half of the emissions locked-in to 2035.** If action were to be delayed until 2015, around 45% of the global fossil-fuel capacity installed by then would have to be retired early or refurbished by 2035. Delaying action is a false economy. For every $1 of investment in the power sector avoided before 2020, an additional $4.3 would need to be spent after 2020 to compensate for the higher emissions.

IEA, *World Energy Outlook 2011 Factsheet* 2 (2011).

This technological challenge is exacerbated by political and socio-economic realities: to alleviate poverty in the developing world, developing countries will need much greater access to energy. Thus, not only will developed countries need to reduce their emissions deeply, but developing and even least developed countries will need to increase energy access in a climate-friendly way.

To meet these challenges, many leading political leaders are calling for dramatic cuts in GHG emissions and a collective effort to retool the energy base of our modern economies to achieve a low-carbon or carbon-free economy. For example, the International Climate Change Task Force has called for a "transformative technological revolution":

> Preventing dangerous climate change . . . must be seen as a precondition for prosperity and a public good, like national security and public health. By contrast, the cost of taking smart, effective action to meet the challenge of climate change should be entirely manageable. Such action need not undermine standards of living. Furthermore, by taking action now and developing a long-term climate policy regime we can ensure that the benefits of climate protection are achieved at least cost. Climate change, energy security, and the urgent need to increase access to modern energy services for the world's poor create an enormous need for more efficient low-carbon and no-carbon energy-supply options. We need a transformative technological revolution in the twenty-first century involving the development and rapid deployment of cleaner energy and transportation technologies. By reducing greenhouse emissions and deploying new climate-friendly technologies, companies can create jobs and launch a new era of economic prosperity.

INTERNATIONAL CLIMATE CHANGE TASK FORCE, MEETING THE CLIMATE CHALLENGE: RECOMMENDATIONS OF THE INTERNATIONAL CLIMATE CHANGE TASK FORCE 1–2 (2005).

The IEA report reinforces the view that technological change must be transformative and revolutionary rather than incremental; if not, we risk locking in technologies for decades, different from the one we need in a carbon-free future. For example, "[b]illion-dollar investments in hybrid auto engines . . . would still leave future motor vehicles dependent on harmful fossil fuel combustion and would retain little market value when polluting nations must eventually convert their automotive transportation systems to GHG-free methods." HOWARD A. LATIN, CLIMATE CHANGE POLICY FAILURES 157 (2012). Similarly, while India is building a coal-fired power plant that reduces GHG emissions by roughly 10 percent compared to traditional power plants, the plant will still emit more than 20 million tons of GHGs per year for decades. *Id.* at 158.

QUESTIONS AND DISCUSSION

1. To date, the climate change negotiations have proceeded on an incremental path with no new climate mitigation commitments scheduled to take effect until 2020. Must the pace of the negotiations increase in order to facilitate a "transformative technological revolution"?

2. Throughout the course of this book, we have described international proposals to mitigate climate change. We have also discussed litigation under current federal law as well as legislative proposals to regulate greenhouse gas emissions. Many of these adopt an incremental approach to climate change. For example, California's successful effort to regulate CO_2 emissions from vehicles, as well as the new federal standard, merely slow the growth in CO_2 emissions. These efforts may begin to shift the economy away from business as usual, but they are inadequate to solve climate change completely. How should environmentalists address this? Should they use their valuable financial and staff resources to slow the growth of greenhouse gas emissions through existing statutes, or should they put their energy and resources into advocacy for the longer term goal of a carbon-free economy?

3. The IPCC has left little doubt that the climate is changing and that human activity is playing a major role in those changes. As noted in Chapter 1, subsequent scientific research shows that climate change is happening faster and some impacts are greater than predicted by the IPCC in 2007. Yet, political leaders appear reluctant to act with the urgency that scientists say is necessary. Is talk of a carbon-free energy sector in 10 years or carbon-free economy within the next 40 years realistic? What approaches that you have learned about in this book do you think hold promise for facilitating a "transformative technological revolution"? What role can law play in such a revolution?

III. HOW TO ACHIEVE A CARBON-FREE FUTURE

In analyzing calls for a transformative energy revolution and a carbon-free future, it is important to revisit the practical possibilities of meeting such a goal. Do we know how to do it? Are there policies and technologies that can help us reach a carbon-free future?

A. Going Carbon-Free with Renewable Sources

In July 2008, former Vice-President Al Gore challenged the United States to produce 100 percent of its electricity from renewable energy and clean carbon sources within 10 years. In making this challenge, Gore invoked President John F. Kennedy's own challenge to land a man on the moon and return him safely to Earth in 10 years — a goal that the United States met in a little more than 8 years. Gore recognized America's antiquated national electric grid and dysfunctional politics. He further recognized that displaced coal miners and others would need assistance as the U.S. electric supply transformed. Yet, he remained optimistic:

> We must now lift our nation to reach another goal that will change history. Our entire civilization depends upon us now embarking on a new journey of exploration and discovery. Our success depends on our willingness as a people to undertake this journey and to complete it within 10 years. Once again, we have an opportunity to take a giant leap for humankind.

Al Gore, Address at D.A.R. Constitution Hall: A Generational Challenge to Repower America (July 17, 2008).

Vice-President Gore's inspirational address did not describe how the United States or any other country could achieve that goal, but it did initiate a discussion as to whether and how that goal could be met. The excerpts from Jacobson and Delucchi examine the feasibility and cost of providing all energy for all purposes (electric power, transportation, heating/ cooling, etc.) worldwide from wind, water, and the sun (WWS). The excerpt from Professor Howard Latin sets forth some clear recommendations for achieving a carbon-free, or at least a low-carbon, energy future. How realistic are these steps? What obstacles do you see that will hold us back?

MARK Z. JACOBSON & MARK A. DELUCCHI, PROVIDING ALL GLOBAL ENERGY WITH WIND, WATER, AND SOLAR POWER, PART I: TECHNOLOGIES, ENERGY RESOURCES, QUANTITIES AND AREAS OF INFRASTRUCTURE, AND MATERIALS

39 ENERGY POLICY 1154, 1164 (2011)

Converting to a WWS energy infrastructure will reduce 2030 world power demand by 30%, primarily due to the efficiency of electricity compared with internal combustion. The amount of wind power plus solar power available in likely developable locations . . . to power the world for all purposes exceeds projected world power demand by more than an order of magnitude.

One scenario for powering the world with a WWS system includes 3.8 million 5 MW wind turbines (supplying 50% of projected total global power demand in 2030), 49,000 300 MW [Concentrated solar power (CSP)] power plants (supplying 20% of demand), 40,000 solar [photovoltaic (PV)] power plants (14%), 1.7 billion 3 kW rooftop PV systems (6%), 5350 100 MW geothermal power plants (4%), 900 1300 MW hydroelectric power plants, of which 70% are already in place (4%), 720,000 0.75MW wave devices (1%), and 490,000 1 MW tidal turbines (1%).

The equivalent footprint area on the ground for the sum of WWS devices needed to power the world is ~0.74% of global land area; the spacing area is ~1.16% of global land area. Spacing area can be used for multiple purposes, including agriculture, ranching, and open space. However, if one-half of the wind devices are placed over water, if we consider wave and tidal devices are in water, and if we consider that 70% of hydroelectric is already developed and rooftop solar areas are already developed, the additional footprint and spacing of devices on land required are only ~0.41% and ~0.59% of the world land area, respectively.

The development of WWS power systems is not likely to be constrained by the availability of bulk materials, such as steel and concrete. In a global WWS-system, some of the rarer materials, such as neodymium (in electric motors and generators), platinum (in fuel cells), and lithium (in batteries), will have to be recycled or eventually replaced with less-scarce materials unless additional resources are located. The cost of recycling or replacing neodymium or platinum is not likely to affect noticeably the economics of WWS systems, but the cost of large-scale recycling of lithium batteries is unknown.

MARK A. DELUCCHI & MARK Z. JACOBSON, PROVIDING ALL GLOBAL ENERGY WITH WIND, WATER, AND SOLAR POWER, PART II: RELIABILITY, SYSTEM AND TRANSMISSION COSTS, AND POLICIES

39 ENERGY POLICY, 1170, 1178–79 (2011)

A 100% WWS world can employ several methods of dealing with short-term variability in WWS generation potential, to ensure that supply reliably matches demand. Complementary and gap-filling WWS resources (such as hydropower), smart demand-response management, and better [weather] forecasting have little or no additional cost and hence will be employed as much as is technically and socially feasible. A WWS system also will need to interconnect resources over wide regions, and might need to have decentralized [vehicle-to-grid (V2G)][1] or perhaps centralized energy storage. Finally, it will be advantageous for WWS generation capacity to significantly exceed peak inflexible power demand in order to minimize the times when available WWS power is less than demand and, when generation capacity does exceed inflexible supply, to provide power to produce hydrogen for flexible transportation and heating/cooling uses. The optimal system design and operation will vary spatially and temporally, but in general will have the lowest-cost combination of long-distance interconnection/transmission, energy storage, and hydrogen production that reliably satisfies intelligently managed (and economically efficient) demand.

The private cost of generating electricity from onshore wind power is less than the private cost of conventional, fossil-fuel generation, and is likely to be even lower in the future. By 2030, the social cost of generating electricity from any WWS power source, including solar photovoltaics, is likely to be less than the social cost of conventional fossil-fuel generation, even when the additional cost of a supergrid[2] and V2G storage (probably on the order of $0.02/kWh, for both) is included. The social cost of electric transportation, based either on batteries or hydrogen fuel cells, is likely to be comparable to or less than the social cost of transportation based on liquid fossil fuels.

Of course, the complete transformation of the energy sector would not be the first large-scale project undertaken in US or world history. During World War II, the US transformed motor vehicle production facilities to produce over 300,000 aircraft, and the rest of the world was able to produce an additional 486,000 aircraft. In the US, production increased from about 2000 units in 1939 to almost 100,000 units in 1944. In 1956, the US began work on the Interstate Highway System, which now extends for 47,000 miles and is considered one of the largest public works project in history. The iconic Apollo Program, widely considered one of the greatest engineering and technological accomplishments ever, put a man on the moon in less than 10 years. Although these projects obviously differ in important economic, political, and technical ways from the

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[1] Eds. note: Vehicle-to-grid (V2G) describes a system in which plug-in electric-drive cars provide electricity to the power grid. Electric-drive vehicles can put out more than 10kW, the average draw of 10 houses.

[2] Eds. note: a supergrid interconnects dispersed generators and load centers.

project we discuss, they do suggest that the large scale of a complete transformation of the energy system is not, in itself, an insurmountable barrier.

We recognize that historically, changes to the energy system, driven at least partly by market forces, have occurred more slowly than we are envisioning here. However, our plan is for governments to implement policies to mobilize infrastructure changes more rapidly than would occur if development were left mainly to the private market. We believe that manpower, materials, and energy resources do not constrain the development of WWS power to historical rates of growth for the energy sector, and that government subsidies and support can be redirected to accelerate the growth of WWS industries. A concerted international effort can lead to scale-up and conversion of manufacturing capabilities such that by around 2030, the world no longer will be building new fossil-fuel or nuclear electricity-generation power plants or new transportation equipment using internal-combustion engines, but rather will be manufacturing new wind turbines and solar power plants and new electric and fuel-cell vehicles (excepting aviation, which will use liquid hydrogen in jet engines). Once this WWS power-plant and electric-vehicle manufacturing and distribution infrastructure is in place, the remaining stock of fossil-fuel and nuclear power plants and internal-combustion-engine vehicles can be retired and replaced with WWS-power-based systems gradually, so that by 2050, the world is powered by WWS. To improve the efficiency and reliability of a WWS infrastructure, advance planning is needed. Ideally, good wind, solar, wave, and geothermal sites would be identified in advance and sites would be developed simultaneously with an updated interconnected transmission system. Interconnecting geographically dispersed variable energy resources is important both for smoothing out supplies and reducing transmission requirements. The obstacles to realizing this transformation of the energy sector are primarily social and political, not technological. As discussed herein, a combination of feed-in tariffs, other incentives, and an intelligently expanded and re-organized transmission system may be necessary but not sufficient [enough to] ensure rapid deployment of WWS technologies. With sensible broad-based policies and social changes, it may be possible to convert 25% of the current energy system to WWS in 10–15 years and 85% in 20–30 years, and 100% by 2050. Absent that clear direction, the conversion will take longer.

To complement the discussion of the technical aspects of a successful transformation of the energy sector, the following excerpt proposes institutional and policy approaches to facilitate the transformation.

HOWARD A. LATIN, CLIMATE CHANGE POLICY FAILURES

162–89 (2012)[*]

The Clean Technology Commission and Development Fund

. . . The development and deployment of GHG-free replacement technologies is the primary goal underlying my proposals, or one might say the lynchpin of my plan, but at least four

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institutions will be needed to implement this mitigation approach: (1) a government-sponsored independent commission composed of leading scientists, engineers, and economists, possibly with a few agency officials. . . . ; (2) a progressively increasing carbon tax intended to raise the money needed to pay for the replacement technology development and deployment functions, and also to provide additional incentives for GHG pollution sources to develop their own clean technologies and to reduce their GHG emissions; (3) a direct-regulation program imposing standards for the best available GHG-free or low-GHG technologies in the sectors that generate the largest amounts of GHG discharges, . . . ; and (4) an inter-agency task force responsible for national or international emissions monitoring and disclosure requirements applicable to all large and medium GHG dischargers. Many climate experts have advocated one or another of these institutional approaches as their main mechanism for overcoming climate change problems, but this chapter contends that we will need all of these overlapping institutions working in a coordinated manner to reinforce each other and improve the chances of successful mitigation outcomes.

The Clean Technology Commission would evaluate the trade-offs among numerous competing GHG-free replacement technologies that may be worth distributing in their present form or improving through additional research and development efforts. The Commission would also oversee the operation of a Technology Development and Dissemination Fund (TDD Fund) to provide sufficient financial assistance for worthwhile clean-technology projects, especially promising innovations developed by private companies with limited fiscal resources.

Some experts claim that existing technologies are sufficient to overcome climate change problems if they are widely adopted, while other experts contend that adequate GHG-free technologies have not yet been demonstrated in many GHG pollution contexts. Rather than asking government officials to guess about which potential GHG-free replacement technologies merit significant support, the Commission would rely on the composite technology assessments and risk assessments of distinguished members chosen primarily from the National Academy of Sciences and the National Academy of Engineering.

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We cannot yet choose which potential clean technologies will become the most effective substitutes for GHG-polluting methods, and it is likely that different GHG-free replacement technologies will prove more or less desirable in different places under different conditions. Someone will have to make the critical GHG-free technology research and development choices and parallel funding choices. Although there are no perfect institutions, I prefer reliance on the Clean Technology Commission’s technological and economic decisions to the alternatives of purely political judgments or market-forces results that are shaped by profitability expectations more than by human and environmental welfare considerations.

* * *

Because we usually cannot predict which GHG-free technologies will prove most effective over time in different contexts, the Commission will need to sponsor numerous design, production, and pilot projects that would enable various clean technologies to compete against each other. However, it is crucial that these GHG-free technologies must not be expected to compete against GHG-based technologies, such as the present energy, transportation, and manufacturing processes that rely on fossil fuel combustion. The fossil fuel producers possess vast financial resources and cannot be allowed to under-price or under-bid nascent clean energy technologies, as they did in the aftermath of the oil crisis of 1973. We must not forget that long-established fossil fuel-based technologies have been the leading anthropocentric cause of global climate change, and we cannot allow the producers of fossil fuels to undermine efforts to create safer GHG-free replacement technologies.

The main functions of the Clean Technology Commission would be to assess, compare, sponsor, and subsidize any array of potential GHG-free technologies while promoting greater market penetration and insulating clean replacement technologies from the commonly distorted market prices and frequently corrupt practices associated with established GHG-based market forces. Alternative GHG-free replacement technologies probably cannot become dominant energy sources without substantial research, development, and marketing subsidies as well as various other kinds of government support.

It is true that government subsidies may be misused to promote the wrong things — this is exactly what has happened with the huge fossil fuel subsidies the US government has been handing out for more than half a century. Proponents of clean energy technologies will have to avoid the misuse of subsidy funds for foolish or selfish purposes, which is an inevitable risk of dealing with our often-frustrating political system. Yet, government leadership and funding for climate change programs is not impossible to imagine, and without substantial government support we probably must give up the game, set, and match.

The Clean Technology Commission cannot perform the various tasks identified above without adequate funding, which explains the requirement for the Technology Development and Dissemination Fund (TDD Fund). In the past decade, many international and national Funds have been created to offer financial assistance for climate change mitigation and adaptation programs.

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Expending a few billion dollars here and a few billion dollars there on many different mitigation missions and institutional preferences is unlikely to produce significant progress anywhere. We should put the great majority of our climate change funding "eggs" into a GHG-free replacement technology "basket" because only that approach can meet the goals of both the developed and developing nations while stabilizing and then reducing the atmospheric GHG concentration. The world's nations need to adopt clean replacement technologies that do not create persistent residual GHG discharges, which is the opposite of the consensus emissions-reduction approaches that have been dominant in the past two decades.

A Progressively Increasing Carbon Tax

The main purpose of this carbon and carbon-equivalent GHG tax are to provide ample funding for the activities of the Commission and TDD Fund, and also to create an additional deterrent incentive that would help persuade polluting sources to reduce their GHG discharges. The former function is crucial for the widespread development and deployment of clean replacement technologies, while the latter function attempts to reduce GHG discharges by gradually increasing their economic costs.

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From the perspective of climate change mitigation, the fundamental problem with [other] carbon tax proposals is that they do not provide funding designated for the development of clean replacement technologies that would reduce the atmospheric GHG concentration and climate change harms. . . .

If we do not use the revenues from the carbon tax to support the functions necessary to design and disseminate affordable GHG-free replacement technologies, where is sufficient funding going to come from? No matter how much we complain about fossil fuels and the long-term damage they are causing, we cannot overcome them without viable alternatives that will probably be quite expensive at the beginning of the technology-replacement process. As a result of the need for substantial financial support, I cannot approve the imposition of any carbon tax or cap-and-trade proposal that fails to allocate a major portion of the net revenues for the purpose of funding the deployment of GHG-free alternative technologies.

The carbon tax revenues may also be needed to support redistributive activities among people who are likely to be disadvantaged by the transition from fossil fuels to clean replacement technologies. . . .

Another important distinction is based on the types of results that these competing economic incentive models would likely yield. The Interstate Highway System was financed by dedicated gasoline taxes that did not evoke much public opposition because people could see the construction of new highways and the practical benefits arising from improved transportation. If my proposals for the TDD Fund applications of carbon tax revenues are adopted, people will similarly be able to see the increasing market penetration of clean GHG-free replacement technologies as they are gradually deployed on a widespread basis. In contrast, the legislatively-proposed cap-and-trade systems are likely to lose their degree of public tolerance much sooner because these programs will lead to "reducing the increases" outcomes that will not yield any meaningful climate change benefits. Taxpayers will hear about numerous trades of GHG allowances, which most people will not be able to understand, and they will hear about the many consultants and speculators who would populate the GHG allowance-grading field, but concerned people will not be able to identify any discernible climate change benefits from the cap-and-trade process. This is true because there will be no tangible benefits . . .

The combination recommended here of progressively increasing carbon taxes and direct pollution-control regulations in high-GHG industrial sectors would create a continuing incentive for firms to reduce their pollution even when an established business, such as an oil company or electric utility, could readily afford to buy the required number of pollution allowances under a cap-and-trade program or to pay the mandated carbon taxes. A major reason why a direct regulation component is included in this multi-institutional plan is to ensure that wealthy GHG dischargers cannot subvert the mitigation program by continuing to put out large amounts of pollution because they are able to buy enough GHG cap-and-trade allowances or to pay the carbon taxes imposed. This is a good illustration of how relying on different but compatible institutions with overlapping responsibilities can help prevent the circumvention or distortion or a regulatory regime by GHG polluters that do not want to clean up their operations.

"Technology-Based" Regulations in High-Pollution Sectors

[The U.S. Environmental Protection Agency (EPA) has adopted a multi-part, multi-source regulatory scheme for GHGs that is complicated and includes too many distinctive categories with too many exceptions that undermine the effectiveness of the GHG regulations. Moreover, it will take several decades for EPA to implement effective technology-based emissions-reduction regulations for this large number of distinctive industries.]

My recommendations would impose [best available control technology] based standards on large and mid-sized GHG polluters in a limited number of industries that in the aggregate represent a substantial majority of the annual GHG dischargers from US sources. All of these industries would have to discharge at least several percent of the cumulative US annual GHG emissions in order to be regulated under this technology-based program. Many of EPA's "Industry Groups for Greenhouse Gas Regulation" . . . would not warrant technology-based regulations under my plan, and instead would be subject only to the carbon tax and mandatory disclosure provisions.

Conversely, most dischargers with GHG volumes below 50,000 tons per year of GHGs will not be regulated or incentivized at all by the EPA rules . . .

Mandatory GHG-Pollution Disclosure Programs

Disclosure programs may be useful as primary institutions in some climate contexts and as supplemental tools in others. . . . [R]egulatory shaming programs can help reinforce deterrence incentives by relying on disclosure requirements and adverse publicity to embarrass major GHG sources and threaten their reputations as cooperative corporate citizens. These disclosure mechanisms could be used to supplement technology-based pollution control standards for some industrial GHG sectors and to supplement the progressive carbon tax for mitigation efforts in other sectors.

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Mandatory disclosure programs could inform consumers and businesses about the worst GHG-polluting products, services, and companies; about the relative status of competing firms in a given industry in terms of their GHG pollution volume per unit of production; about the best energy-efficient products and GHG-free product choices for consumer purchases; about behavioral and recreational practices that are especially harmful from a climate perspective; and about the existence of an increasingly wide range of clean alternative products and services. I do not believe that we could depend primarily on consumers to reduce most GHG emissions resulting from their daily behaviors, but GHG disclosure programs would enable those people who are seriously or casually concerned with climate change impacts to make appropriate purchasing decisions that can influence the competitive choices of polluting businesses whose perceived "goodwill" is at stake.

. . . It is difficult to see how economic-incentives or market-forces regimes could succeed unless they are supported by extensive disclosures from companies that are significantly damaging the climate, because "willingness to pay" assessments cannot be effective without consumers having sufficient knowledge about what they want to pay for.

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Many other disclosure mechanisms are possible, and the specific requirements will have to be selected and refined by the responsible regulatory agencies. In early 2010, for example, the US Securities and Exchange Commission (SEC) acting on behalf of potential investors decided "to require publicly traded companies to disclose information regarding business risks and opportunities related to climate change." These kinds of GHG disclosure programs should be regarded as overlapping mechanisms that can support the other mitigation institutions by creating stronger incentives for large GHG sources to reduce their discharges or to shift to GHG-free technologies in the near future. These programs may also help all polluters, both consumers and businesses, make better choices about their own mitigation options. This discussion emphasizes that disclosure programs can help improve the performance of other kinds of mitigation programs, and in some GHG contexts they could serve as the primary mechanisms for promoting better climate-related decisions.

QUESTIONS AND DISCUSSION

1. Others have come to the same conclusions as Delucchi and Jacobson. For example, the World Wildlife Federation concluded that

> it is technically feasible to supply everyone on the planet in 2050 with the energy they need, with 95 per cent of this energy coming from renewable sources. . . . [T]he scenario . . . mapped out is practically possible. It is based only on the technologies the world already has at its disposal, and is realistic about the rate at which these can be brought up to scale. Although significant investment will be required, the economic outlay is reasonable, with net costs never rising above 2 per cent of global GDP. . . . [A] fully renewable energy future is not an unattainable utopia. It is technically and economically possible, and there are concrete steps we can take — starting right now — to achieve it.

WORLD WILDLIFE FOUNDATION ET AL., THE ENERGY REPORT: 100% RENEWABLE BY 2050 23, 85 (Stephan Singer et al. eds., 2011). How can the law be used to catalyze major investments in WWS to make this carbon-free future a reality? What are the most important obstacles in your view to a successful transformation of the energy sector?

2. Others, in agreeing that the transformation of the energy sector to non-carbon sources is realistic, also point out that a decentralized energy system, composed of millions, even billions, of power sources, will "empower" citizens, both literally and figuratively, by distributing wealth across a much broader spectrum of society than the fossil-fuel industry, which is dominated by just a few companies.

> In the new era, businesses, municipalities and homeowners increasingly become the producers as well as the consumers of their own energy — so-called "distributed generation." Just as the distributed communication revolution of the last decade spawned network ways of thinking, open-source sharing, and the democratization of communications, a post carbon society follows suit with the democratization of energy.

Maria da Graça Carvalho et al., *Building a Low Carbon Society*, 36 ENERGY 1842–47 (Apr. 2011).

3. Analysis by Chatham House in 2009 concluded that "inventions in the energy sector have generally taken two to three decades to reach the mass market." The reasons were numerous: slow capital stock turnover, risk aversion when financing large capital projects, private sector business strategies and a high degree of complexity in the energy system. BERNICE LEE, WHO OWNS OUR LOW CARBON FUTURE? INTELLECTUAL PROPERTY AND ENERGY TECHNOLOGIES vii (Chatham House, Sept. 2009). Yet,

> transformative change cannot be achieved by domestic action alone. Cross-border trade and investment in low carbon and energy-efficient goods, services and technologies need to be encouraged and scaled up. Stimulating low carbon trade will create virtuous cycles, creating further investment opportunities and expanding the market for key technologies.

Id. at 55. What kind of international cooperation would you propose to bring about this transformative change? Does Professor Latin provide a model for doing so? Does the UNFCCC's Climate Technology Centre and Network do so?

4. A carbon tax of $30 per ton of CO_2 — the current price in British Columbia — could generate about $145 billion a year in the United States. Many carbon tax proponents highlight the tax's role in reducing personal income or corporate income taxes. *See, e.g.*, Yoram Bauman & Shi-Ling Hsu, *The Most Sensible Tax of All*, N.Y. TIMES, July 4, 2012. The political benefits of this approach are obvious. Yet, Professor Latin takes a different approach: He would dedicate these resources to financing technological change. Which approach do you think is better?

5. ***Building Political Will for Preventing Climate Change.*** What should become clear from the above excerpts as well as a review of mitigation strategies in Chapter 2 is that in general terms a consensus exists for what needs to be done to reduce the risk of the worst climate change impacts — an ambitious expansion of energy conservation and fuel switching to non-fossil fuels. Most of the technologies necessary to make this energy transformation already exist, although the costs of some must decline to compete with business-as-usual energy sources or technologies. From a legal perspective, many of the necessary policies are also familiar, involving some combination of taxing carbon, reducing subsidies to fossil fuels, capping and trading emissions, and mandating restrictions or technologies on specific industries. The problem is thus not a lack of smart technologies or policies but rather a lack of political will. How should this political will be built?

Some observers, such as Gus Speth, former head of United Nations Development Programme and founder of the World Resources Institute, believe we need to build a stronger environmental movement. He argues that environmentalists must broaden their agenda and join with others to address not just traditional environmental issues but also those issues "unraveling America's social fabric and undermining its democracy," such as soaring executive pay, increasingly concentrated wealth for a small minority, poverty rates near a thirty-year high, and shrinking safety nets, among other issues. Doing so will require a major grassroots effort that embraces and brings together union members and working families; minorities and people of color; religious, scientific, and student organizations; the women's movement; and enlightened business leaders. JAMES GUSTAVE SPETH, THE BRIDGE AT THE EDGE OF THE WORLD: CAPITALISM, THE ENVIRONMENT AND CROSSING FROM CRISIS TO SUSTAINABILITY 225–31 (2008).

Others believe the use of language and the way we frame the debate — is climate change an environmental issue or a human health imperative? — could help build momentum for a carbon-free future. Reframing the debate about climate change reflects the growing recognition that *how* we talk about issues has a significant impact on *whether* there will be political support for action. How we talk or frame an issue reflects certain values and ideas, which may or may not be values and ideas shared by the majority of the public. If responding to climate change is viewed as merely one more environmental issue, it may arguably never garner sufficient popular support for the transformative steps that are necessary. Would it be better, then, to think of climate change as a public health issue? As a national security issue? Or as an economics and jobs issue? President Obama has frequently noted that investments in renewable energy will create 5 million new jobs. Professor Lisa Heinzerling believes that framing climate change as a human health issue will give climate change a "human face," motivate political action, enlarge the number and kinds of governmental institutions involved in the problem, and create a strong moral case for action. First, she points out that efforts to eliminate DDT in the United States succeeded only when DDT was tied to human cancer; effects on wildlife alone were insufficient to motivate political action. Second, she argues that calling climate change a public health issue will force us to think differently about solutions to climate change, in part because non-environmental institutions, such as the Centers for Disease Control and the National Institutes of Health, will need to become involved. Third, the moral case for climate change action becomes "unimpeachable" if "humans are dying and falling ill due to our collective actions, and will continue to do so in even larger numbers if we do nothing." Worries about polar bears, she argues, will not bring about this moral clarity *See, e.g.*, Lisa Heinzerling, *Climate Change, Human Health, and the Post-Cautionary Principle*, 96 GEO. L.J. 445, 450–451 (2008).

You are the senior staff attorney for a major environmental organization that works on climate change issues. Your Executive Director has asked for advice on how to build support in the United States for converting the supply of electricity to 100% renewables by 2050. Review the many impacts of climate change outlined in Chapter 1. How do you think your organization should frame climate change to build support for this plan? Will you frame the issue as a human rights issue like the Inuit in their claim described in Chapter 11? As a national security issue as the Pentagon views it? Of course, climate change implicates all of these issues, which is what makes it so urgent and such an exciting area of law. Can you build a campaign that incorporates a number of these ideas? What risks does such an approach entail?

6. Climate change of course touches all sorts of issues and can be framed in many different ways. Environmental groups are sensitive to this, which is why almost every environmental group working on climate change uses the polar bear as an iconic symbol for the environmental threats of climate change. Why do you think environmentalists place so much attention on the polar bear? Is this a good strategy for environmental groups? What constituency is attracted to such an approach? On the one hand, such an approach may speak to the core environmental constituency, but does it help create a broader social movement like that envisioned by Gus Speth?

7. There are many exciting opportunities emerging for law students and others interested in working towards the transformative changes necessary to address the challenge of climate change. All major national environmental organizations now have climate change programs. State and local organizations also are promoting climate change policies throughout the country. In addition, many state and municipal governments are creating commissions, counsels, and new departments to cut their carbon footprints. *See* Chapter 17. The carbon markets are also creating exciting new opportunities for business-minded lawyers. Virtually every large law firm now has special climate counsel. Many private sector corporations are trying to cut their emissions and participate in the emerging carbon market. And even small businesses and individual households are building demand for energy audits and carbon offsets. At each of these levels, there is a need for climate lawyers.

8. Climate change is a dynamic area of the law, with laws and policies in flux at all levels. Internationally, the post-Kyoto regime may have been completed within a year or two of this book's publication. For certain, President Obama will continue to use his executive power to substantially change federal policy on climate change. State and local governments, unless preempted by federal law, show no sign of slowing their efforts to mitigate climate change. To what extent do changes since the publication of this book give you hope that the world and the United States may effectively meet the climate change challenge? In light of these recent developments, what would you now say is the highest priority for lawyers and policymakers?

B. The Nuclear Option

Nuclear power poses a significant dilemma, particularly for environmentalists, as society wrestles with options for a carbon-free future. Nuclear power is essentially carbon-free: nuclear power does not result in any direct CO_2 emissions, and its indirect CO_2 emissions are comparable to the indirect emissions from most renewable energy sources. At the same time, when things go wrong, as they did at Chernobyl in 1986 and Fukushima in 2011, things go very wrong, creating serious environmental and human health problems. Is nuclear power an attractive option for a carbon-free future or are its potential environmental and human impacts too great to make it a viable option?

NUCLEAR ENERGY AGENCY & NUCLEAR ENERGY AGENCY, THE ROLE OF NUCLEAR ENERGY IN A LOW-CARBON ENERGY FUTURE

Summary and Conclusions, 85–90 (OECD 2012), at www.oecd-nea.org/nsd/reports/2012/nea6887-role-nuclear-low-carbon.pdf*

As an established source of low-carbon energy, nuclear power could potentially play a vital role in achieving large reductions in CO_2 emissions while ensuring reliable and affordable energy supplies. This is illustrated by scenarios such as the International Energy Agency's Blue Map scenario, which models a 50% cut in energy-related CO_2 emissions. It includes around 1200 [Gigawatts of electrical output (GWe)] of nuclear capacity by 2050, or some 24% of global electricity supply. This presumes that a large-scale and broadly-based expansion of nuclear capacity will take place, such as occurred during the first major nuclear expansion of the 1970s and 1980s.

It is clear . . . that nuclear energy could make a major contribution to future cuts in CO_2 emissions if it is able to provide around one-quarter of global electricity supply by 2050. To reduce CO_2 emissions from electricity supply by over 90% by 2050 would require this nuclear expansion to occur alongside an even more rapid expansion of renewable energy capacities, the large-scale introduction of carbon capture and storage technology at fossil-fuelled power plants, and major improvements in energy efficiency.

Nuclear presently provides around 13.4% of global electricity, a figure which has been in decline in recent years as its growth has not matched the overall growth in electricity supply. Although this decline may continue for a few more years, the significant upturn in nuclear plant construction starts that was observed between 2008 and 2010 could indicate a halt in the decline in nuclear share of total electricity production. In 2011, the number of construction starts dropped to 4 from 16 in 2010, possibly as a combined effect of the Fukushima Daiichi accident and the economic crisis. It is too early to assess the trend in 2012, but it is worth noting that for the first time in more than 30 years, the United States has decided to launch the construction of new nuclear build, with the Combined Construction and Operating Licences being granted by the US [Nuclear Regulatory Commission] for 4 Generation III+ reactors in 2 sites.

However, for nuclear energy to provide a growing share of global electricity by 2020 and beyond, the pace of nuclear construction would need to further increase in the next few years. Hence, the key question for the future of nuclear energy is whether it can expand quickly enough over the next decades to provide a growing share of total electricity supply as the use of fossil fuels is cut back in order to reduce CO_2 emissions.

The analysis in this study indicates that to meet the capacity milestones mentioned above towards a nuclear capacity of 1200 GWe in 2050, new nuclear power plants would need to be built at the rate of close to 16 GWe per year over the current decade to 2020. This is a little greater than the rate that was observed at the end of 2010, when 63 GWe was under construction (equivalent to an annual rate of about 13 GWe, assuming a 5-year construction period).

* * *

Factors affecting nuclear expansion

The study has not identified any insurmountable barriers to an expansion of nuclear generating capacity on the scale required over the next 40 years. However, despite the clear opportunity for nuclear energy to expand as the use of fossil fuels is cut back, many challenges to such a rapid expansion remain. If nuclear energy is to realise its full potential, then governments and the nuclear and electricity supply industries would need to successfully address these.

* * *

The principal challenges for nuclear expansion over the next ten years include:

- The difficulties of financing the high capital costs of nuclear plants, especially given the risk of delays and cost overruns with first-of-a-kind plants and in countries with no recent experience of nuclear construction.
- Overcoming current constraints on industrial capacities and human resources for the construction of nuclear plants.
- Recovering pre-Fukushima levels of public acceptance of nuclear energy, by addressing people's concern over the safety of nuclear power.
- Demonstrating the safe management of radioactive wastes, and implementing plans for the disposal of long-lived high-level waste.
- Introducing nuclear capacity into additional countries while avoiding the proliferation of sensitive nuclear materials and technologies.
- Increasing the supply of nuclear fuel in line with the expansion of nuclear capacity, and ensuring reliable fuel supplies during reactor lifetimes of 60 years.

The regulatory reviews that were ordered in countries operating nuclear power plants after the Fukushima Daiichi accident are expected to result in additional requirements on nuclear plant designers and operators. This could lead to delays and increased costs for nuclear construction projects, though it is too early to quantify these impacts. At the same time, it could be beneficial to public acceptance of nuclear power by showing that safety suffers no compromise, and remains the highest priority for governments, regulators and operators.

* * *

In the longer term, other issues may come to the fore. Nuclear energy is today a source of baseload electricity, i.e. nuclear plants are mostly in operation constantly at full power. In a largely decarbonised electricity supply system (containing mainly renewables, nuclear energy and fossil fuel plants with CCS), nuclear plants may increasingly need to adapt their output to complement that of intermittent renewable[s] . . . The gradual introduction of smart grids at both transmission and distribution levels will also impact the demands on generating plants. New designs of nuclear plant will thus need to take account of these changing requirements.

* * *

Responding to the challenges

A successful nuclear programme in any country must have the confidence of society as a whole. Nuclear plant operators are responsible for ensuring they achieve high standards of operational safety and performance. This must be backed up by strong and independent regulatory authorities. Furthermore, transparency and public involvement in decision-making are vital to ensure public acceptance for nuclear programmes. This encompasses issues such as radioactive waste management and disposal, nuclear safety, and avoiding the proliferation of sensitive nuclear materials and technologies. . . .

[S]trong and sustained government policy support is a prerequisite for nuclear expansion. Governments must also create the appropriate legal, regulatory and market conditions in which investment in new nuclear capacity can take place if they intend to rely on the nuclear option. They must work with industrial partners to ensure that the decision-making and regulatory processes work effectively and efficiently. Harmonisation of regulatory requirements between countries would have important benefits, helping to reduce construction times and costs by allowing near-identical plants to be built in many countries.

Although studies have shown that nuclear energy is one of the most cost-effective sources of electricity on a lifetime cost basis, the scale of investment in an individual nuclear power plant, and hence the period required to make a return on investment, is generally much larger than for other types of generating plant. This creates particular problems for those seeking to finance investment in new nuclear plants, driving up the financing costs compared to fossil-fuelled generating capacity. This is especially true where such investment is to be made principally by the private sector and where competitive electricity markets exist. At least in the early stages of nuclear expansion, some form of government support for financing costs may thus be required in some cases.

WORLD WILDLIFE FOUNDATION ET AL., THE ENERGY REPORT: 100% RENEWABLE BY 2050

19 (Stephan Singer et al. eds., 2011)

[W]e cannot escape the reality that nuclear fission produces dangerous waste that remains highly toxic for thousands of years — and there is nowhere in the world where it can be stored safely. The United States and Germany alone have accumulated more than 50,000 and 12,000 tonnes respectively, of highly radioactive waste which has not yet been disposed of securely. According to the U.S. Environmental Protection Agency, it will be at least 10,000 years before its threat to public health is substantively reduced.

Equally troubling, the materials and technology needed for nuclear energy can also be used to produce nuclear weapons. In a politically unstable world, spreading nuclear capability is a dangerous course to take.

Nuclear is no 'easy' technology. It requires a highly sophisticated and trained staff, and only works on a large scale, providing power around the clock. It is certainly not a viable way to provide electricity for the 1.4 billion people whom are currently denied it, many of whom live in remote places in fragile states.

Nuclear power is also an extremely expensive option. Before pouring billions into creating a new generation of nuclear power stations, we need to ask whether that money would be better invested in other, sustainable energy technologies.

QUESTIONS AND DISCUSSION

1. Three Mile Island, Chernobyl, Fukushima. These names are synonymous with catastrophe and tragedy. For example, a steam explosion at Reactor #4 at the Chernobyl nuclear power station on April 26, 1986, killed 31 operators and firemen within three months and several others later. At least 134 people were diagnosed with acute radiation syndrome (ARS), 28 of whom died within a few weeks of the accident. Another 19 people died between 1987 and 2004, although their deaths were not dispositively shown to be caused by radiation exposure. A large number of children developed thyroid cancer, likely due to intake of radioactive iodine fallout, with about 4,000 Chernobyl-related cases diagnosed and treated since 1986. Large areas of Belarus, Ukraine, and Russia were contaminated and remain off limits to human use of any kind; 250,000 people were permanently relocated. In Belarus, approximately 44,000 sq. km (21 percent of the country's surface area) remains contaminated with radioactive cesium-137; 21,000 sq. km (10 percent of the surface area) is contaminated with strontium-90; and 4,000 sq. km (2 percent of the surface area) is contaminated with plutonium isotopes. Smaller areas in Ukraine and Russia are also contaminated. Somewhere between 100,000 to 200,000 people continue to live in severely contaminated areas of Belarus, Ukraine, and Russia. These impacts were caused by the release into the atmosphere of perhaps just 5 percent of the radioactive reactor core. For more information, see United Nations, *United Nations and Chernobyl*, at http://www.un.org/ha/chernobyl/undocs.html.

The accident at the Three Mile Island Unit 2 on March 28, 1979 caused no deaths or injuries to plant workers or members of nearby communities. Also, "comprehensive investigations and assessments by several well-respected organizations have concluded that in spite of serious damage to the reactor, most of the radiation was contained and that the actual release had negligible effects on the physical health of individuals or the environment." Nuclear Regulatory Commission, *Backgrounder on the Three Mile Island Accident* (Aug. 2009).

In contrast, coal mining killed 100,000 workers in the 21st century and even today kills an average of six people each day in China. Natural gas can explode. Hydroelectric dams collapse, frequently force the relocation of thousands of people, and cause significant environmental damage as reservoirs fill pristine valleys. Wind power kills thousands of birds and bats. Yet it is nuclear power that is stigmatized. Why?

2. The journalist William Tucker puts the nuclear challenge in the context of resource use. He notes that a six-ounce uranium fuel rod can produce enough energy to power a city the size of San Francisco for five years. Whereas a nuclear reactor must be refueled by a fleet of six trucks arriving once every two years, a coal plant must be fed by a 100-car freight train arriving every 30 hours. There are 283 coal mines in West Virginia and 449 in Kentucky. There are only 45 uranium mines in the entire world. Russia is offering to supply uranium to most of the developing world with the output from one mine. Hydro, wind, and solar power each require vastly greater amounts of land to generate equivalent power than nuclear power does. For example, "[r]eplacing just one of the two 1,000-megawatt reactors at Indian Point in Westchester County, N.Y., would require lining the Hudson River from New York to Albany with 45-story windmills one-quarter mile apart—and then they would generate electricity only about one-third of the time, when the wind is blowing." William Tucker, *Why I Still Support Nuclear Power, Even After Fukushima*, WALL STREET JOURNAL (Apr. 23, 2011). Do you find these arguments compelling?

3. Balancing risk and uncertainty is particular challenging with respect to nuclear power. Even if the risks of catastrophe are very small, they are not zero, as the accidents at Chernobyl and Fukushima starkly illustrate. With 440 reactors operating around the world, there have been just three major accidents at nuclear power plants. On the other hand, even if William Tucker is correct that wind and solar power have a much larger landscape footprint than nuclear power, the risk of catastrophe is zero. How does this information affect the mix of non-carbon energy you think is appropriate in a non-carbon future?

4. As WWF points out, nuclear power plants produce highly toxic waste for thousands of years. If nuclear energy continues to provide 20 percent of U.S. electricity needs through the end of this century, the United States would need nine additional repositories the size of the proposed repository at Yucca Mountain in Nevada. As Burton Richter notes, locating and operationalizing these repositories would be very challenging since the United States has not been able to open Yucca Mountain. Burton Richter, *Nuclear Energy, in* CLIMATE CHANGE SCIENCE AND POLICY 467, 471 (Stephen Schneider et al., eds. 2010).

5. Another concern regarding the use of nuclear power is the potential to enhance nuclear weapons capacity. As one author writes, "it is well understood that one of the factors leading several countries now without nuclear power programs to express interest in nuclear power is the foundations that such programs could give them to develop weapons." Harold A. Feiveson, *A Skeptic's View of Nuclear Energy*, DAEDALUS, Fall 2009. Another writes that "a robust global expansion of civilian nuclear power will significantly increase proliferation risks unless the current non-proliferation regime is substantially strengthened by technical and institutional measures and its international safeguards system adequately meets the new challenges associated with a geographic spread and an increase in the number of nuclear facilities." Ioannis N. Kessides, *Nuclear Power: Understanding the Economic Risks and Uncertainties*, 38 ENERGY POLICY 3849, 3860 (2010). The link between nuclear power generation and nuclear weapons development in India, Pakistan, Iran, and North Korea would appear to support these concerns. How does it affect your opinion of whether a carbon-free future includes nuclear power?

IV. GEOENGINEERING

In the climate change context, geoengineering is the intentional, large-scale manipulation of the planet's climate. As the evidence of climate change impacts mounts, ideas of re-engineering the planet's basic ecosystems — ideas once dismissed as ridiculous — are now gaining more interest and credibility. And as climate change impacts worsen due to wholly inadequate efforts to avoid climate change, geoengineering proponents can make increasingly plausible arguments that we may have no other choice than to use geoengineering at least to some extent. Some geoengineering proposals, like releasing trillions of tiny mirrors or building a refracting mirror from one hundred million tons of lunar glass on the moon, sound like science fiction and are currently only theoretical possibilities, although seriously considered. Others, however, such as launching sulfates or other aerosols into the upper atmosphere to deflect solar radiation or fertilizing the oceans with iron to enhance carbon sequestration, are already technically feasible, relatively easy to understand, and in some cases already the subject of design studies or pilot tests. All of these proposals also raise, in varying degrees, the possibility of significant adverse impacts that need to be considered in evaluating the potential for geogengineering.

A. What is Geoengineering?

Geoengineering is an expansive term encompassing a wide array of proposals for mitigating the effects of global warming through the deliberate, large-scale manipulation of various environmental systems. What sets geoengineering apart, as suggested by the following excerpt, is the focus on intent and scale:

> While the scope of human impact is now global, we have yet to make a deliberate attempt to transform nature on a planetary scale. I call such transformation geoengineering. More precisely, I define geoengineering as intentional, large-scale manipulation of the environment. Both scale and intent are important. For an action to be geoengineering, environmental change must be the goal rather than a side effect, and the intent and effect of the manipulation must be

> large in scale. Two examples demonstrate the roles of scale and intent. First, consider intent without scale: Ornamental gardening is the intentional manipulation of the environment to suit human desires, yet it is not geoengineering because neither the intended nor realized effect is large-scale. Second, consider scale without intent: Climate change due to increasing carbon dioxide (CO_2) has a global effect, yet it is not geoengineering because it is a side effect of the combustion of fossil fuels to provide energy. Pollution, even pollution that alters the planet, is not engineering. It's just making a mess.
>
> Manipulations need not be aimed at changing the environment, but rather may aim to maintain a desired environment against perturbations — either natural or anthropogenic. Indeed, the term has most commonly been applied to proposals to engineer climate, so as to counteract climate change caused by rising CO_2 concentrations. In this context, . . . geoengineering implies a countervailing measure or a "technical fix"; an expedient solution that uses additional technology to counteract unwanted effects without eliminating their root cause.

David W. Keith, *Geoengineering*, *in* CLIMATE CHANGE SCIENCE AND POLICY 494, 494 (Stephen Schneider et al., eds. 2010).

Geoengineering proposals fall within two distinct categorical approaches to the problem of global warming: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM). CDR methods sequester CO_2 or other GHGs from the atmosphere, such as through ocean fertilization with iron and the enhanced weathering of rocks and the construction of artificial trees to sequester CO_2. SRM involves either deflecting sunlight to reduce the solar radiation reaching Earth or enhancing the albedo — or reflectivity — of the atmosphere, clouds, or Earth's surface. SRM strategies reduce the sun's energy input without reducing atmospheric GHG levels.

Currently, all of the proposed geoengineering strategies have major uncertainties in their costs, effectiveness, or associated risks, and they are unlikely to be ready for deployment for many years. Nonetheless, some are based on relatively proven technologies, while others assume dramatic advances in technology and would be very expensive. The following outlines a cross-section of geoengineering proposals.[3]

1. *Carbon Dioxide Removal (CDR)*

Most CDR proposals, such as large-scale afforestation and reforestation, are not considered to be geoengineering. They are simply larger-scale versions of otherwise common land-use practices. However, the following CDR proposals employ technology or other large-scale manipulations of the environment and constitute geoengineering.

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[3] The summary derives largely from ROYAL SOCIETY, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY (Sept. 2009). This report is, among other things, an excellent summary of the literature on geoengineering up to the date of publication.

Sequestration of biomass and biochar. These two strategies involve intervening in the natural cycle to increase the amount of carbon fixed by organic matter and stored in soils or elsewhere for hundreds or thousands of years. In one proposal, wood and agricultural waste would be buried on land and in the deep ocean to store the carbon rather than allowing these materials to decompose and release their carbon to the atmosphere. Biochar (charcoal) is created typically by heating organic matter — for example, wood, leaves, food wastes, straw, and manure — as it decomposes in a low-oxygen environment. Through this process, the carbon atoms in charcoal are bound together much more strongly than in plant matter, making it resistant to decomposition by micro-organisms.

Enhanced weathering. As carbonate and silicate rocks weather (a processes called dissolution), they remove CO_2 from the atmosphere. While this process naturally takes place over many thousands of years, geoengineering proposals would speed up the process by mining and grinding the mineral olivine, a magnesium iron silicate, and dumping the ground mineral onto agricultural fields and elsewhere. A volume of about 7 km^3 per year (approximately twice the current rate of coal mining) of such ground silicate minerals, mined and ground to react with CO_2, could remove as much CO_2 as is currently emitted annually (it takes approximately two tons of rock to remove and store one ton of CO_2). Other proposals call for reacting carbonate rocks with CO_2 at industrial facilities and dumping the resulting bicarbonate solution into the ocean, which would reduce the acidity of ocean water and thus slow ocean acidification.

Carbon dioxide capture from ambient air. Still other ideas propose to capture CO_2 from ambient air for subsequent use or disposal. While no large-scale demonstrations have yet been produced, several small-scale laboratory tests using different methods have proved effective.

Oceanic upwelling or downwelling modification methods. Because carbon is naturally transferred to the deep sea through upwelling and circulation of the oceans, some proposals seek to increase upwelling rates by pumping water from a depth of several hundred meters to the surface or increase downwelling of dense water in the subpolar oceans. Because most CO_2 is transported to the deep sea by the circulation of ocean waters (and not by sedimentation of organic matter), proponents assume that increasing this circulation will sequester carbon by transferring it to the deep sea more quickly.

Ocean Fertilization. In recent years, two private companies have been actively pursuing the widespread distribution of fixed nitrogen, phosphate, and iron particles in certain parts of the ocean, depending on which nutrient is considered to be the limiting nutrient for absorbing CO_2. Fertilization with nitrogen might sequester six carbon atoms for each atom of nitrogen added and one atom of phosphate might sequester roughly 100 atoms. More promisingly, one atom of iron has the possibility to stimulate production of 100,000 organic carbon atoms. ROYAL SOCIETY, at 17. The amount of carbon actually sequestered, however, is variable, depending on ocean currents and other factors. Scientists warn that most carbon

> is in fact rapidly returned to its inorganic mineral form (remineralised) as a result of respiration in surface water and elsewhere, and only a small fraction is

> finally transported and sequestered deep in the water column or in the sediments. As a consequence, most of the proposals concerning ocean fertilization have focused on iron fertilization.

Id. This iron would fertilize the ocean, causing rapid growth in certain algae that would consume significant amounts of CO_2. As the algae die, they would sequester this CO_2 on the ocean floor. Depending on the scale, ocean fertilization may or may not always be considered geoengineering, but would need to occur on a massive scale to provide any climate change benefits.

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2. *Solar Radiation Management (SRM)*

Like CDR strategies, SRM strategies suffer from a paucity of real-life data to affirm their efficacy. Unlike CDR strategies, SRM strategies leave CO_2 and other GHGs in the atmosphere. Instead, SRM strategies rely on diminishing solar radiation from reaching or being absorbed by Earth.

Cloud-albedo enhancement. Some have proposed whitening clouds over the oceans where atmospheric areas are relatively dust-free. Seeding these areas with cloud-condensation nuclei enhances cloud formation and could raise cloud albedo "significantly" and increase the cloud lifetime "possibly." According to these estimates, a doubling of the natural cloud-droplet concentration in all low-level marine clouds (covering approximately one-quarter of the ocean surface) would increase the cloud-top albedo sufficiently to compensate approximately for a doubling of atmospheric CO_2.

Desert reflectors. Some have suggested covering deserts with a reflective polyethylene-aluminum surface. Estimates suggest that this would increase the mean albedo from 0.36 to 0.8 and have a radiative forcing of -2.75 W/m^2. To have this kind of effect, however, roughly 10 percent of Earth's land surface would need to be covered.

Sulfate Aerosols. Several proposals have been made to launch sulfate or aluminum particles into the atmosphere to scatter or reflect incoming light from the sun, which shades and cools the Earth's surface by preventing solar energy from hitting the planet's surface. Such proposals are based on the documented impacts of volcanic eruptions like that of the 1991 eruption of Mount Pinatubo in the Philippines, which lowered the earth's average temperature by about 0.5ºC in the year following the eruption. Sulfate aerosols could be added to the emissions of power plants or to the fuel emissions from commercial airliners. The advantage of such methods is that the climate response of albedo enhancement would occur within a matter of months. A reduction of solar input by about two percent would balance the effect on global mean temperature of a doubling of CO_2. Some rely on the Mount Pinatubo eruption as evidence that this strategy holds great promise. Some observers suggest that artificially creating a Mount Pinatubo eruption every two years "would be sufficient to offset much of the anthropogenic warming expected over the next century," and would "present minimal climate risks." T.M.L. Wigley, *A Combined Mitigation/Geoengineering Approach to Climate Stabilization*, 314 SCIENCE 452, 452–53 (2006).

Orbiting Reflectors. Other proposals would use orbiting mirrors or other reflective materials to deflect solar radiation away from Earth. One proposal is to release millions of tiny hydrogen-filled mylar balloons into an orbit 25 kilometers above the surface. Another proposal would launch 55,000 orbiting mirrors, each approximately 100 square kilometers to reflect solar energy away from the earth. Proposals also exist to ring the planet with satellites or a particle ring like that found around Saturn. These proposals, using lower orbits, would require a total mass of dust particles of over 2 billion tonnes to achieve a reduction in solar insolation (the amount of sun reaching a given location over a given period of time) of about 2 percent. That is approximately the amount of radiative forcing required to compensate for a doubling of CO_2.

Solar Orbiting Reflectors. Further afield (or more precisely further in space) are proposals to orbit a reflector around the sun — about 1.5 million kilometers from Earth. These solar shields propose the use a superfine mesh of aluminum threads, a trillion or so thin metallic reflecting disks, or ten trillion extremely thin refracting disks. To provide roughly a two percent reduction in solar irradiance reaching the Earth, the effective area of the sunshades would need to be about three million km^2. A separate proposal would build a refractor on the Moon and be composed of a hundred million tons of lunar glass.

QUESTIONS AND DISCUSSION

1. CDR methods are, in some senses, more "natural" than SRM strategies. They also address the core climate change issue more directly by removing GHGs from the atmosphere. As such, CDR strategies tend to look like other mitigation strategies already employed by many UNFCCC Parties, such as reforestation projects or pollution control technologies that remove CO_2 or other GHGs from industrial processes. Moreover, if implemented on a large enough scale, global net emissions could be negative. However, CDR strategies focusing on CO_2 would take "several decades before they would actually have a discernable effect on climate, even if it were possible to implement them immediately." ROYAL SOCIETY, at 47. On the other hand, SRM strategies could significantly reduce average global temperatures within years. Before choosing a particular CDR or SRM strategy, what other information would be helpful?

2. What is your view of the potential for geoengineering as an approach to climate change? What arguments for or against the intentional manipulation of the earth's climate do you find compelling?

B. The Geoengineering Debate: Urgency, Uncertainty, and Unintended Consequences

Each of these geoengineering proposals, even the more prosaic among them, raises significant legal, ethical, economic, and governance issues. Many policymakers are fearful that time and resources spent in developing and debating geoengineering proposals will detract from the higher priority of avoiding emissions in the first place.

The most important argument for geoengineering is simply that we may have no choice if we hope to avoid catastrophic impacts from anthropogenic climate change. To be sure, the potential impacts from climate change outlined in Chapter 1 argue persuasively for looking at all feasible options. In light of the growing climate threat, it becomes less likely with each passing year that relying solely on the reduction of greenhouse gas emissions will enable us to avoid substantial economic and ecologic dislocation. While not suggesting that we reduce efforts to mitigate climate change, some geoengineering proponents argue that we need to evaluate all possible responses and need to be testing the more promising geoengineering approaches, at least as a sort of short-term insurance policy against cataclysmic climate change. As argued below, geoengineering proponents also argue that, at least as compared to some cost estimates for reducing GHG emissions, some geoengineering proposals are cost effective.

The anticipated timelines for climate change also argue for a closer look at geoengineering. Even if we are able to muster the political will to make deep cuts in CO_2 emissions and move significantly towards a carbon-neutral era, this may not be done in time to avoid significant climate impacts. We may need to bridge the gap between the time when emissions are reduced substantially and the decline of atmospheric concentrations of GHGs. These timing considerations may change the risk analysis around geoengineering options. Even if some unintended (and unknown) consequences are likely from geoengineering, those risks must be measured against the unintended (and unknown) consequences of living for that same period of time with an atmosphere exceedingly high in CO_2 and other GHGs. Which uncertain world are we more willing to live in? Particularly, if geoengineering is viewed as a temporary step, the risk analysis could swing in its direction.

Opponents of geoengineering rebut many of the proponents' arguments, but add significant arguments about the ethics and uncertainty of tinkering so fundamentally with Earth's life support systems. Deliberately manipulating the planetary climate regime reflects, to some, an act of hubris beyond almost anything humanity has tried before. Although we have undoubtedly changed Earth's climate through human activities, that has been (at least until recently) without intent. To *intentionally* try to manage Earth's climate takes climate change into a different set of ethical debates. The "end of nature" is no longer an accident, but a decision. BILL MCKIBBEN, THE END OF NATURE (1989).

Beyond ethical issues are arguments about the unintended consequences that may occur from any deliberate manipulation of the climate system. Many scientists do not believe that we have sufficient knowledge about the planet to predict what potentially serious impacts could occur from most geoengineering proposals. Purporting to evaluate the potential benefits and costs of geoengineering processes paints geoengineering discussions with a patina of legitimacy that may, in some views, not be warranted by the state of scientific knowledge. The potential unknowns are substantial and in fact may make matters worse — we may be "swallowing the spider to catch the fly." For many ecologists, the record of human intervention in trying to improve nature is rich with examples where the best of human intentions have resulted in significant calamities. Often these calamities have been felt in local ecosystems (for example, with the deliberate introduction of invasive species to control other invasive species). Geoengineering has the potential for massive mistakes. As described below, significant questions remain concerning the environmental impacts of even the most cost-effective and best-studied geoengineering options.

Many climate change observers fear that focusing on geoengineering will distract policymakers from making the hard decisions to reduce GHGs by essentially granting GHG polluters a "get out of jail free" card. This problem, known as the "moral hazard" argument, posits that those protected from risk will engage in risky or riskier behavior. In this context, geoengineering insures GHG emitters from taking action to mitigate emissions. Similarly, it could divert efforts and funding — both public and private — away from clean technologies that would reduce GHG emissions. And it could lull the general public into thinking that we do not need to make the difficult cultural and economic decisions necessary to address climate change.

In this context, opponents fear that we will become addicted to geoengineering. If, in fact, we do not take the steps necessary to substantially reduce GHG emissions, then any reliance on geoengineering will be forever and the commitment to use geoengineering only as a temporary fix will be forgotten.

Whatever the climate benefits may be from CDR and SRM geoengineering strategies, they all currently have significant potential environmental impacts. Because of the lack of tests — indeed many strategies, such as placing a refractor on the moon, cannot realistically be tested at all — scientists have had to use modeling studies to identify potential environmental impacts.

For SRM techniques that are meant to shade the planet or "manage" solar radiation (for example, with aerosol particles), however, there is one very significant, known problem — the "termination problem." That is, because these techniques do not reduce GHG concentrations but simply mask the impacts of GHGs, once the strategy is ended (or fails for some unforeseen reason), temperatures will rapidly warm due to the influx of solar radiation that would be trapped by high, unmitigated GHG concentrations. With no time for natural adaptation to occur, such rapid temperature increases might have particularly severe impacts. Moreover, such screening techniques will not reduce ocean acidification, altered growth rates of plants, and other impacts from elevated CO_2 concentrations. These impacts are a direct result of increasing concentrations of CO_2 in the atmosphere and independent of climate change or temperature. To the extent that a geoengineering strategy, for example sun-shading or aerosol scattering, does not reduce atmospheric GHG concentrations, it will not reduce ocean acidification or changes to plant growth rates.

Even the known potential negative impacts of SRM techniques are significant. A recent study showed that, along with cooling, volcanic eruptions also brought global drought and corresponding record reductions in runoff and river discharge. In addition, the eruption of Mount Pinatubo led to a 2 percent reduction in stratospheric ozone. According to models, injections of sulfur dioxide to enhance stratospheric aerosol would reduce precipitation in Asia and Africa with potential impacts on the food supply for billions of people. Moreover, it is not clear what public health impacts, including those resulting from lower stratospheric ozone levels, might come from annually sending the equivalent of a volcano's worth of particulate matter into the atmosphere.

The space-based SRM techniques not only seem far-fetched, but they are also decades away from implementation. They also entail such "great uncertainties in costs, effectiveness (including risks) and timescales of implementation that they are not realistic potential contributors to short-term, temporary measures for avoiding dangerous climate change." ROYAL SOCIETY, at 33. Models also indicate that they would have regional climate effects, particularly on hydrological cycle.

CDR strategies provide a different set of environmental problems. Rather than affecting climate and weather patterns, such as more or less precipitation in particular regions, the impacts of CDR activities would involve changes to habitats and ecosystems. For example, mining 7 km^3 of silicate rock annually is certain to have significant local impacts. Burying biomass in the land or the deep sea will consume energy for transport, burying, and processing. Most seriously,

> the processes involved may disrupt growth, nutrient cycling and viability of the ecosystems involved. In the deep ocean, for example, organic material would be decomposed and the carbon and nutrients returned to shallow waters, since oxygen is generally present (unless sufficient material were deposited to create anoxic conditions, which would constitute a major ecosystem perturbation). Full assessments are not yet available to assess the costs and benefits involved but it seems unlikely that this will be a viable technique at any scale that could usefully reduce atmospheric carbon.

ROYAL SOCIETY, at 11.

Moreover, the impacts of CDR activities will be sustained over long periods of time — "decades and more probably centuries" — to compensate for an annual release of 8.5 GtC per year from fossil fuel burning alone. According to the Royal Society, "[i]t is very unlikely that such approaches could be deployed on a large enough scale to alter the climate quickly, and so they would help little if there was a need for 'emergency action' to cool the planet on that time scale." ROYAL SOCIETY, at 9–10.

Iron fertilization, perhaps the best-known CDR activity given 12 small test studies, highlights the scale, uncertainty, and limited utility associated with CDR activities. Consider that the ocean's entire, current biological pump is responsible for sinking approximately 10 GtC per year out of the ocean's surface layer, "of which only a fraction sinks deep enough to be sequestered for centuries." Even if iron fertilization could increase this figure by 10 percent, which would require a massive fertilization program, only some fraction of 1 GtC/yr extra could be extracted from the atmosphere. As human activities currently generate 8.5 GtC per year, even a massive iron fertilization program would contribute modestly to reducing CO_2 concentrations. Given the large amounts of iron that would need to be added to the marine environment, "there are likely to be unintended and probably deleterious ecological consequences." ROYAL SOCIETY, at 17, 19.

QUESTIONS AND DISCUSSION

1. Most of the environmental impacts described above are speculative, although based on the best available scientific information, including sound knowledge about how oceanic and atmospheric cycles work. Still, we have very little understanding of geoengineering's real impacts and their scale. Indeed, the possibility remains that completely unanticipated impacts may occur. Critics contend that climate change is itself the unintended effect of technologies once considered safe and that responding with large-scale deployment of new technologies could exacerbate the problem. Do you agree that the "cure could be worse than the disease"? Or are the known effects of further climate change so great that a leap of faith in these geoengineering techniques is warranted? How should the precautionary principle apply to our consideration of the geoengineering?

2. To help policymakers make choices about which, if any, geoengineering techniques to pursue, the Royal Society advances two concepts — encapsulation and reversibility:

> *Encapsulation* refers to whether the method is modular and contained, such as is the case with air capture and space reflectors, or whether it involves material released into the wider environment, as is the case with sulphate aerosols or ocean fertilisation. Encapsulated technologies are sometimes viewed as more ethical in that they do not involve releasing 'foreign material' into the environment. This is not to suggest that encapsulated technologies may not have environmental impacts: depending on the nature, size and location of the application, there may be direct and indirect impacts, for example on habitat, landscape and/or species, or unintended consequences on other elements of the climate system. Furthermore, the application or effects of methods may have transboundary consequences, especially if such activities are located near the border with another State.
>
> *Reversibility* refers to the ability to cease a technological programme and have its effects terminate in a short time. In principle, all of the options considered in this report could be abandoned. Air capture technologies could be switched off instantly and have no further climate effect. With other methods, for example sulphate aerosols or ocean fertilisation, there may be a time lag after abandonment for the effects of methods to cease, if they have caused environmental changes. However, the issue of reversibility applies to more than just the ability to 'switch off' the technology. The solar radiation management (SRM) methods for example do not affect the greenhouse gases in the atmosphere and if efforts to remove CO_2 are not undertaken in parallel, the abandonment of such methods would result in a rapid temperature rise. And while there would be no immediate ill-effect from 'switching off' air capture technologies, any moves to abandon these technologies could meet strong resistance due to the investments made in construction and maintenance of the physical infrastructure; just as getting vested interests to abandon the use of fossil fuels is a challenge for conventional mitigation.

ROYAL SOCIETY, at 38–39. Using these concepts, which SRM or CDR techniques do you think should be pursued? At what point (e.g., tipping points) do some techniques become more attractive?

3. The space-based proposals seem too far-fetched to be taken seriously. Nonetheless, many view them as potentially valuable contributors to combating climate change if long-term geoengineering techniques are needed. Not only might they be less environmentally risky (at least on earth), but they may also be cost-effective — a few trillion dollars — compared to other options; they may also have a much longer lifetime. With a sizeable portion of U.S. space exploration coming to a close with the retirement of the space shuttles, should the U.S. National Aeronautics and Space Administration shift its resources towards realizing space-based SRM techniques?

C. Geoengineering Economics

For many, one of the attractive features of geoengineering, in particular SRM strategies such as aerosol spraying, is that it is inexpensive and, many commentators assume, "present[s] minimal climate risks." T.M.L. Wigley, *A Combined Mitigation/Geoengineering Approach to Climate Stabilization*, 314 SCIENCE 452, 452 (2006). Others, however, are less certain, arguing that the costs are highly speculative because "we currently understand very little about either the potential utility or the risks of reducing absorbed solar radiation" and that "unanticipated negative impacts on human and ecological systems could overshadow the expected benefits." JASON J. BLACKSTOCK ET AL., CLIMATE ENGINEERING RESPONSES TO CLIMATE EMERGENCIES 2, 3 (Novim, July 29, 2009). As such, the "extent to which methods involving large-scale manipulation of Earth systems (such as ocean fertilisation), can sequester carbon affordably and reliably without unacceptable environmental side-effects, is not yet clear." THE ROYAL SOCIETY, at x. Consider the following arguments.

SCOTT BARRETT, THE INCREDIBLE ECONOMICS OF GEOENGINEERING

39 ENVTL. RESOURCE ECON. 45, 49–50 (2008)

The economics of geoengineering are — there is no better word for it — incredible. Upon reviewing the options in depth, the Panel on Policy Implications of Greenhouse Warming concluded by saying that, "one of the surprises of this analysis is the relatively low costs at which some of the geoengineering options might be implemented." The Panel calculated that adding stratospheric aerosol dust to the stratosphere would cost just pennies per ton of CO_2 mitigated. Drawing on this study, Nordhaus concluded that offsetting all greenhouse gas emissions today would cost about $8 billion per year — an amount so low that he treats the geoengineering option as being costless. According to Teller et al., engineered particles would be even cheaper (mainly because of the reduced volume of material that would need to be put into the stratosphere); they estimate that the sunlight scattering needed to offset the warming effect of rising greenhouse gas concentrations by the year 2100 would cost just $1 billion per year. Keith thinks this is an optimistic estimate, but says that, "it is unlikely that cost would play any significant role in a decision to deploy stratospheric scatterers because the cost of any such system is trivial compared to the cost of other mitigation options."

Taking into account the effect of engineered particles on scattering harmful UV radiation, Teller and his colleagues calculate that this health-related benefit for the U.S. alone would exceed the total cost of geoengineering by more than an order of magnitude. If correct, the economics are even more favorable than suggested above. Deliberate climate modification would also allow carbon dioxide concentrations to remain elevated — an aid to agriculture.

Just as important as the cost of geoengineering relative to emission reductions is the nature of these two options. Geoengineering constitutes a large project. By means of this technology, a single country, acting alone, can offset its own emissions — and those of every other country. By contrast, mitigating climate change by reducing emissions requires unprecedented international cooperation and very substantial costs. Stabilizing atmospheric concentrations requires a 60–80% cut in CO_2 emissions worldwide. In the years since the Framework Convention on Climate Change was adopted, global emissions have risen about 20%. Even if the Kyoto Protocol is implemented to the letter, global emissions will keep on rising. So will concentrations. Theory points to the difficulty in achieving substantial and wide scale cooperation for this problem, and the record to date sadly supports this prediction.

A quick calculation hints at the temptation presented by geoengineering. According to Nordhaus and Boyer, climate change might cost the United States alone about $82 billion in present value terms. Using a three percent rate of discount, this is equivalent to an annual loss of about $2.5 billion. If the U.S. cut its emissions, it could reduce this damage somewhat. If it turned to geoengineering, it could eliminate this damage. If geoengineering is as cheap and effective as is claimed, the U.S. might prefer the geoengineering option. So, of course, might other countries.

. . . Even if the costs turn out to be much higher . . . and no country has an incentive to try geoengineering unilaterally, a coalition of . . . countries would have an incentive to do so collectively . . .

MARLOS GOES ET AL., THE ECONOMICS (OR LACK THEREOF) OF AEROSOL GEOENGINEERING

109 CLIMATIC CHANGE 719 (2011)

One general problem with aerosol geoengineering is that it attempts to balance the radiative forcing of CO_2 with the counterforcing by stratospheric aerosols. These two forcings have vastly different climate response times because stratospheric aerosols have a life-time of a few years while CO_2 in the atmosphere has a lifetime of centuries to millennia. A failure to maintain the aerosol counterforcing (for example in the case of a war, a breakdown of an international agreement, or the discovery of sizable negative effects due to the aerosol forcing) would lead to an abrupt warming with rates that are unprecedented for modern human societies and would likely cause sizeable economic damages. A second risk of aerosol geoengineering is that the resulting polar ozone depletion would damage natural and managed ecosystems and human health. A third risk is that aerosol geoengineering will not counteract ocean acidification, which is caused by the reaction between CO_2 and sea water. Ocean acidification can negatively impact coral reefs and pelagic populations that depend on them. Finally, variations in the concentration of stratospheric aerosol affect the properties of climate system components such as El Niño, precipitation- and temperature-patterns, and the Asian and African summer monsoon. This brief discussion of geoengineering risks is certainly not exhaustive, but arguably sufficient to make the point that an analysis of geoengineering strategies needs to account for geoengineering risks.

* * *

Given the aforementioned caveats, we draw from our analysis three main conclusions. First, aerosol geoengineering hinges on counterbalancing the forcing effects of greenhouse gas emissions (which decay over centuries) with the forcing effects of aerosol emissions (which decay within years). Aerosol geoengineering can hence lead to abrupt climate change if the aerosol forcing is not sustained. The possibility of an intermittent aerosol geoengineering forcing as well as negative impacts of the aerosol forcing itself may cause economic damages that far exceed the benefits. Aerosol geoengineering as a substitute for abatement can hence pose considerable risks to climate and economy. Second, substituting aerosol geoengineering for CO_2 abatement can fail an economic cost-benefit test in our model over a wide range of so far deeply uncertain parameter values. In contrast, (and as shown in numerous previous studies) fast and sizeable cuts in CO_2 emissions (far in excess of the currently implemented measures) pass a cost-benefit test. Third, aerosol geoengineering not carefully balanced by CO_2 abatement constitutes a conscious temporal risk transfer that arguably violates the principle of intergenerational justice. Fourth, whether geoengineering is deployed in an economically optimal portfolio hinges on currently deeply uncertain assumptions. Even if we assume that the probability of intermittent aerosol geoengineering is zero (an arguably very optimistic assumption), aerosol geoengineering is sometimes deployed only many decades in the future and is limited to small counter-forcing. The magnitude and timing of aerosol geoengineering in this case hinges on the so far deeply uncertain estimates of damages due to the aerosol forcing.

QUESTIONS AND DISCUSSION

1. Sir Nicholas Stern estimated the costs of mitigation to be roughly one percent of global GDP by 2050, or about \$1 trillion per year, to avoid our current annual emissions of about 10 $GtCO_2$/yr. STERN REVIEW: THE ECONOMICS OF CLIMATE CHANGE 239 (2007). This corresponds to a carbon price of around \$100 per ton of carbon or \$27 per ton of CO_2. Stern's estimate assumes stabilization of CO_2 concentrations at 500 to 550ppm CO_2eq, and thus may underestimate costs. Now consider the estimated costs of geoengineering suggested by Barrett. Does geoengineering look more attractive now, even recognizing that accurate cost estimates for geoengineering technologies are extremely tentative in the absence of real-world testing?

2. Marlos Goes et al. also put the costs of deploying aerosol geoengineering in the absence of other mitigation strategies within the framework of intergenerational justice:

> In so quantifying the harms of intermittent aerosol geoengineering, we clarify the nature of the risk that would be transferred from current to future generations through such a policy decision. This information, combined with scientific understanding of the impacts of the abrupt warming due to a discontinuation of the aerosol forcing upon human communities and ecosystem integrity, clearly illustrate that this policy would put at risk the conditions required to satisfy basic welfare rights of future generations. Since intergenerational justice requires that current generations avoid policies that create benefits for themselves but impose burdens on future generations, substituting aerosol geoengineering for CO_2 abatement arguably fails this basic principle of intergenerational justice given the potentially severe risks associated with a potential discontinuation of aerosol geoengineering.

Does this information change your view of the costs and benefits of geoengineering?

3. Some geoengineering commentators have suggested that geoengineering is acceptable only as an option of last resort. This view rejects the possibility of using geoengineering techniques even if they could stabilize atmospheric GHG concentrations at lower costs than traditional forms of mitigation, such as energy efficiency. Why should geoengineering only be used as an option of last resort, or put another way, only in extreme circumstances? How would you define "option of last resort" or "extreme circumstances"?

D. Governance and the Current State of the Law

Despite the potentially urgent need for and significant environmental impacts of geoengineering techniques, the UNFCCC has not attempted to address the issue. Moreover, no other international institution or treaty regime has a mandate broad enough to regulate these activities generally. In the absence of a single legal framework, customary international law such as the duty not to cause environmental harm may provide a framework for resolving disputes involving transboundary impacts from geoengineering activities such as sulfate aerosol techniques or cloud enhancement. *See* Chapter 11, Section I. The United Nations Law of the Sea Convention, with its obligation to protect the marine environment and compulsory dispute settlement, may provide the legal machinery for resolving disputes concerning ocean fertilization. *See* Chapter 9, Section V.

The absence of a framework for addressing geoengineering took on greater urgency when private companies began actively exploring the possibility of sequestering carbon by fertilizing the ocean with iron in order to remove carbon and sell the carbon removal credits in the global carbon offset market. Thus far, at least twelve open-ocean experiments have been held, ranging from 1 to 4 weeks, with 1 to 2 tons of elemental iron, covering approximately 100 km^2 in the ocean. These experiments have been inconclusive on the effectiveness of ocean iron fertilization, which has led some in the scientific community as well as the private companies to expand the experiments to 10,000 km^2, using 10 to 20 tons of iron so they can analyze the full growth cycle of plankton and find out where the carbon actually ends up (at the bottom or surface of the ocean). *See* Carli Ghelfi, *Despite Opposition, Ocean Iron Fertilization Forging Ahead*,CLEANTECH.COM, June 10, 2008; Philip Boyd et al., *A Mesoscale Phytoplankton Bloom in the Polar Southern Ocean Stimulated by Iron Fertilization*, 407 NATURE 695, 695–702 (Oct. 12, 2000); Martin LaMonica, *Ocean Fertilization Firm Climos Gains Financial Backing, available at* http://news.cnet.com/8301-11128_3-9886183-54.html, Mar. 5, 2008; Rachel Petkewich, *Fertilizing the Ocean with Iron*, 86 CHEMICAL & ENGINEERING NEWS, Mar. 31, 2008, at 30.

For obvious reasons, the companies' plans to discharge such large amounts of iron deliberately into the oceans raise questions under international law. To the extent that these experiments with iron fertilization involve the use of ships, the international regime relating to ocean pollution could also play a role. The Convention on Biological Diversity, which directs Parties to conserve biological diversity including marine biodiversity, could also play a role.

1. *The 1972 London Convention*

Operational discharges, spills, and intentional dumping from ships are an important source of pollution to the marine environment and at least eight international agreements address threats posed by vessel pollution and dumping. The most relevant for iron fertilization is the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, signed Dec. 29, 1972, 1046 U.N.T.S. 120 (entered into force Aug. 30, 1975) (known as the 1972 London Convention).

In 2010, the London Convention Parties adopted an "Assessment Framework for Scientific Research Involving Ocean Fertilization" which provides a tool for assessing proposed activities on a case-by-case basis to determine if a proposed activity constitutes legitimate scientific research. Resolution LC-LP.2(2010), on the Assessment Framework for Scientific Research involving Ocean Fertilization (Adopted on 14 October 2010); Assessment Framework for Scientific Research involving Ocean Fertilization, LC 32/15 Annex 6. The Parties also agreed that this framework was only a start and that they must continue to develop "a global, transparent, and effective control and regulatory mechanism for ocean fertilization activities" that may harm the marine environment. Resolution LC-LP.2(2010), para. 5.

QUESTIONS AND DISCUSSION

1. At its 2010 meeting, the London Convention Parties also made their clearest statement that ocean fertilization research activities fall within the scope of the London Convention and Protocol and are not otherwise exempted from the definition of "dumping." Resolution LC-LP.2(2010), para. 6.

2. Greenpeace was important in bringing this issue to the attention of the London Convention Parties and, as seen in Chapter 9, Section IV environmental groups led the efforts within the World Heritage Convention to bring climate change issues before that Convention's Parties. Can you see how environmental groups can play an important monitoring and agenda-setting role? Do you think Greenpeace received everything it wanted as part of the London Convention process?

3. Not all marine scientists endorse the idea of a moratorium on large-scale iron fertilization experiments. Some scientists believe experiments of at least 200 km^2 in size are necessary to understand the impacts on ocean ecology. They also objected to the CBD's statement limiting experiments to coastal areas. Moreover, they do not want to foreclose the possibility of conducting other experiments that could be important for understanding the oceans. *See* Intergovernmental Oceanographic Commission, Statement of the IOC Ad Hoc Consultative Group on Ocean Fertilization, June 14, 2008.

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2. *Convention on Biological Diversity*

The Parties to the Convention on Biological Diversity (CBD) have expressed their concern about the potential impacts of iron fertilization as a step to mitigate climate change. In 2010, the CBD Parties provided the following guidance:

> (w) Ensure, in line and consistent with decision IX/16 C, on ocean fertilization and biodiversity and climate change, in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities[3] that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment;
>
> [3] Without prejudice to future deliberations on the definition of geo-engineering activities, understanding that any technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere) should be considered as forms of geo-engineering which are relevant to the Convention on Biological Diversity until a more precise definition can be developed. It is noted that solar insolation is defined as a measure of solar radiation energy received on a given surface area in a given hour and that carbon sequestration is defined as the process of increasing the carbon content of a reservoir/pool other than the atmosphere.

Decision X/33, *Biodiversity and Climate Change*, para. C.8(w) (Oct. 29, 2010).

QUESTIONS AND DISCUSSION

1. Previously, in 2008, the CBD had effectively imposed a moratorium, a decision that inhibits research, while also recognizing the current absence of reliable data concerning ocean fertilization. Since iron fertilization must be massive to have any appreciable climate impact, the CBD decision would appear to make it impossible to obtain the type of information that the CBD Parties need to make decisions concerning iron fertilization. Does the 2010 Decision remedy this concern? Given the large unknowns about iron fertilization, what would you recommend as a possible means to safely explore the use of iron fertilization?

2. The CBD's decisions are considered nonbinding. What legal effect, if any, does the CBD decision have on the status of ocean fertilization? What effect, if any, would it have on private efforts to engage in iron fertilization?

3. United Nations General Assembly has also weighed in on iron fertilization. In 2008, it "*encourage[d]* States to support the further study and enhance understanding of ocean iron fertilization." U.N.G.A. Resolution 62/215, *Oceans and the Law of the Sea*, A/RES/62/215, para. 98 (Mar. 14, 2008). The London Convention has 87 Parties, the CBD has 193 Parties, and the United Nations has 193 members. Which of these institutions should regulate iron fertilization? Which should regulate geoengineering more generally? The UNFCCC, with its 195 Parties, is perhaps the most obvious choice. Even so, given the history of the UNFCCC, is it the appropriate one? If not, then is there an existing institution capable of doing it? Would you create a new one?

4. Several commentators have called for scientists engaged in geoenginnering to agree on a voluntary code of conduct and system for approval for geoengineering research. Do you agree? What do you think should be included in such a code of conduct?

5. The commercial sector has already shown great interest and made investments in some geoengineering strategies. Some of these strategies, such as biochar, air capture and surface albedo enhancement, can be contained with a single State territory with few if any negative transboundary effects. What existing laws might apply to such activities?

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3. *Other Governance Strategies*

We are many years away from using geoengineering as a large-scale mitigation strategy, with all methods requiring "significant research including in some cases, pilot scale trials, to establish their potential effectiveness and effects on climatic parameters including temperature and precipitation at both the global and regional scales." ROYAL SOCIETY, at 36. For now, perhaps the minor contributions of the London Convention and CBD are sufficient. Yet, iron fertilization, sulfate aerosols, and perhaps other strategies are likely affordable for many States as well as some corporations and wealthy individuals. What should the international community do if, as some believe is reasonably possible, a State unilaterally deploys a geoengineering strategy to mitigate its GHG emissions. Recall that the Cancun Agreements do not limit the choices that the

Parties use to meet their pledges, and the Parties have not otherwise adopted a resolution on geoengineering. Thus, it is theoretically possible that a State could use geoengineering to meet its pledge. Beyond establishing research protocols or outright bans, what options do governments have for regulating geoengineering?

One option is the environmental assurance bond, a policy approach that has been proposed for a number of activities that may have uncertain, but potentially serious environmental impacts. With environmental assurance bonding, regulated entities post a bond equal to the best estimate of the *largest* potential environmental damages before commencing an activity. The bond is returned to the entity if it can "demonstrate that the suspected worst-case damages had not occurred or would be less than was originally assessed." Robert Costanza & Laura Cornwell, *The 4P Approach to Dealing with Scientific Uncertainty*, ENV'T, at 12, Nov. 1992. If environmental impacts do occur, then bond funds are used to pay for remediation activities and compensate injured parties. Bidisha Banerjee assesses the use of environmental assurance bonding in the geoengineering context. Scott Barrett takes a different approach, assessing the institutional capacity of the climate change regime to prevent countries from deploying geoengineering strategies unilaterally or in small groups.

BIDISHA BANERJEE, THE LIMITATIONS OF GEOENGINEERING GOVERNANCE IN A WORLD OF UNCERTAINTY

4 STAN. J. L. SCI. & POL'Y 15, 33–35 (2011)*

Kysar argues that environmental assurance bonding (EAB) offers a middle-of-the-road regulatory perspective in cases where both risks and benefits are poorly understood. Noting that such bonds would be price-equivalent to the worst-case threats posited by the scheme, Kysar claims that this approach exhibits an equal degree of humility towards both sociolegal and biophysical systems. Unlike an outright ban, which would preclude any possible benefits of the research, a bond could incentivize researchers to move from uncertainty (which has no standard measure) to risk (which does). However, Kysar does note that environmental assurance bonds have not worked effectively thus far, primarily because regulators have been unwilling to demand the full value of the bonds. Moreover, Gerard and Wilson note, "Being able to estimate remediation costs is a crucial component for setting the bond amount." Without a more comprehensive epistemic shift in the regulatory framework, it is difficult to see how this problem could be circumvented.

Furthermore, the particular characteristics of geoengineering may make assurance bonding prohibitively difficult to implement, at least in the case of SRM attempts. Environmental assurance bonding would require a geoengineering project to post a bond "equal to the current best estimate of the largest potential future environmental damages." This is ideally suited to, say, a mining project, where the surety company's exposure can be calculated based on local effects and knowledge accumulated over hundreds of years. In the SRM case, the vastness of the

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worst-case harms and the degree of uncertainty makes it hard to imagine who would put up a bond. Depending on the level of certainty required and the method by which numerous non-economic harms (the loss of small island nations or cultures, for example) were valued, EAB can, to some extent, degenerate into two familiar limit cases: a prohibitive precautionary approach or a permissive cost-benefit analysis. Environmental assurance bonding may be easier to implement in the CDR and sequestration contexts, however. Even in the SRM case, its conceptual features and incentive shifts should be studied closely. If governments, and not private firms, were engaging in SRM, perhaps more comprehensive assurances (of relocation assistance, foreign aid, and so on) could substitute for the strictly economic nature of a bond.

If these challenges could be overcome, civil society groups could embrace the idea of EABs for specific geoengineering research projects. This could have the additional benefit of resolving the tension between scientific erasure of socio-political realities and context-specific, place-based meaning-making that Jasanoff highlights in her technologies of humility rubric. Demanding environmental assurance bonding would sharpen civil society engagement with geoengineering and elevate the dialogue beyond the broad allegations of groups like Geoengineering Watch, which are easy for scientists to dismiss. Egede-Nissen and Venema additionally suggest a role for the Arctic Council in encouraging more public participation in and construction of a dialogue about geoengineering interventions in the Arctic. Even if EAB simply shifts the battle between precaution and prohibition to a new territory, that territory may be less intellectually and politically deadlocked than the one in which we find ourselves at present.

SCOTT BARRETT, THE INCREDIBLE ECONOMICS OF GEOENGINEERING

39 ENVTL. RESOURCE ECON. 45, 50–53 (2008)[*]

Ironically, the attributes that make geoengineering attractive also make it worrying. Because it consists of a single project, it can be undertaken unilaterally or minilaterally. Because of its low cost, the incentives for it to be tried are very strong. The consequences of one country or a small number of countries using it, however, would be global; and they might not all be welcome.

So, who is to decide whether geoengineering should be deployed? Should a country be allowed to do so unilaterally? Could it be prevented from doing so? Some countries are expected to benefit from climate change, at least gradual climate change through this century. According to Nordhaus and Boyer, for example, Russia, China, and Canada would all gain. Would these countries need to be compensated for damages resulting from a geoengineering intervention to limit climate change? If the losers from climate change use geoengineering to cool temperatures, might the winners use geoengineering to *absorb*, rather than to scatter, radiation? (Might there be geoengineering wars?) Could *they* be prevented from doing so? Would countries be allowed to engineer any temperature, or would they only be permitted to limit change from the recent

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historical average? The world's poorest countries are especially vulnerable to climate change, and yet they are likely to be the least able to develop and deploy a geoengineering effort. Should the more capable states be required to do so for them? Should they be made to pay compensation if they do not? Suppose geoengineering affected the spatial distribution of climate, even if it succeeded in preventing the global (average) climate from changing. Should the countries adversely affected be compensated? How would damages be determined? Which countries would be expected to pay compensation? How could the obligation to pay be enforced? What about countries that have different attitudes towards risk, or that object to the idea of deliberately altering the climate whatever the benefits may be? Should their views be heeded?

Two precedents offer a glimpse into how these concerns might be addressed. The first concerns experiments with a different kind of particle. The Large Hadron Collider being built in Europe is intended to test the Standard Model of particle physics. The knowledge gained from this project will be a global public good, but there is a small chance that the experiment could create something called a strangelet — an object that, by a process of contagion, might possibly "transform the entire planet Earth into an inert hyperdense sphere about 100m across." It is even conceivable that the particle smashes might create a growing black hole — a phenomenon that might destroy not just the Earth but the entire universe. A report written for the backers of the Large Hadron Collider concludes that there is "no basis for any conceivable threat." But the likelihood of a strangelet being created is impossible to calculate with certainty, since the experiment has never taken place before. Existing theories are reassuring, but they have not been tested. And do we really want to test them? Are we sure that the global public good of new knowledge outweighs the global public bad of the risk of annihilation? More importantly, who should decide whether the experiments should go ahead? So far, the decision has been left to the parties that are financing the project — the 20 European members states of CERN (officially, the European Organization for Nuclear Research), the organization that is building and that will run the Large Hadron Collider, and its partners on this project — India, Japan, Russia, and the United States. But should other countries have been consulted? Should other countries have a veto?

The second precedent concerns the remaining stocks of smallpox virus. Smallpox was eradicated in 1977, yielding every country a huge dividend. Provision of this global public good meant that people no longer needed to die of this disease. It meant also that there was no longer a need for people to be vaccinated. Unfortunately, reaping this dividend has exposed countries to a new risk. If smallpox were somehow reintroduced today, the world would be more vulnerable than ever to an epidemic. So long as smallpox exists, this risk remains. Concern about a possible accidental release caused laboratories around the world to destroy or transfer their stocks; by 1983, known stockpiles of smallpox virus were held by just two World Health Organization (WHO) "collaborating centers," one in Atlanta and the other in Moscow. But were these the *only* remaining stocks left? Unfortunately, no one could be sure. Some people suspected that covert stocks might have been retained by other states. That concern persists today.

What to do with the last two known stockpiles? In 1986 and again in 1990, the WHO's Committee on Orthopoxvirus Infections recommended that the stocks held in Atlanta and Moscow should be destroyed. But while destruction would eliminate the risk of an accidental release, it would also foreclose the option of using the remaining stocks to develop improved diagnostic tools, antiviral drugs, and a novel vaccine — innovations that would benefit the whole world should covert stocks exist and should smallpox virus be released deliberately some day. As with geoengineering, the decision to destroy the remaining stores of smallpox entails a risk-risk tradeoff. It also has implications for every country.

Again the question: Who should decide? The two states that possess the virus obviously have the upper hand (just as the major powers would have the upper hand in developing a geoengineering project), but being WHO collaborating centers, the labs in Atlanta and Moscow are obligated to serve the global interest.

In 1998, the WHO polled its 190 members. Did they want the last known stocks to be retained or destroyed? The survey revealed a split. Russia wanted to hold onto its samples; Britain, France, Italy, and the United States were undecided; every other country (74 other countries responded) favored destruction. Concerned about the risk of a bioterrorist attack, the United States changed its position in 1999, asserting a need to keep its stockpile. When the World Health Assembly met shortly after this, a compromise was worked out. A resolution was proposed that reaffirmed the goal of *eventual* destruction but permitted Russia and the U.S. to retain their stocks for research purposes for a period of three years. The resolution passed by acclamation. Later the reprieve was extended; and, today, smallpox virus is still kept at the two WHO centers. Inspectors have satisfied the WHO's Advisory Committee on Variola Virus Research that the stocks are secure, and the Committee has verified that the research undertaken at both labs has progressed. They have also confirmed, however, that the job is not yet finished. Their judgment is that there is still reason to retain smallpox for research purposes.

The arrangements surrounding the decision to retain the smallpox stocks are very different from those connected with the conduct of possibly dangerous experiments. The latter are being undertaken by a relatively small number of countries, without wider consultation let alone approval. The smallpox decision, by contrast, has been undertaken in a setting in which all the world's countries were invited to take part. To be sure, in this case the power relations among countries are vastly unequal. But the process that emerged favored consensus — an especially fortunate outcome. Since every country will be affected by whatever is decided, it is as well that each should agree with the decision.

As matters now stand, the situation with geoengineering is more akin to the regime for carrying out particle collider experiments than to the smallpox decision. Currently, there is no institutional arrangement that says what countries are allowed to do or not to do as regards geoengineering. By default, therefore, countries are pretty much free to explore geoengineering options or not as they please. It may be unlikely that countries would seek to act unilaterally, or as part of a "coalition of the willing," but that possibility will remain unless and until climate engineering is brought into an institutional framework of some kind.

How to proceed? Three steps are needed. First, the possibility of geoengineering should be examined in detail by the Intergovernmental Panel on Climate Change, in a special report. Its pros and cons need to be evaluated, and all countries need to be made aware of them. Second, and drawing on this technical work, the Framework Convention on Climate Change should be revised. This agreement has the great advantage of having nearly universal participation (the only non-parties are Andorra, Brunei, the Holy See, Iraq, and Somalia, and these states are free to join when their circumstances permit). Currently, however, the Framework Convention embraces the objective of stabilizing atmospheric concentrations of greenhouse gases; it does not mention geoengineering. A revised convention should emphasize the need to reduce climate change risk — a broader objective that would encompass not only efforts to reduce atmospheric concentrations but also adaptation (which is mentioned in the Convention), R&D into new energy technologies, and geoengineering. Finally, and building upon the first two steps, a new protocol should be added that specifies whether and under what conditions geoengineering should be allowed (even if only for research purposes), or possibly even required, and how the costs of any efforts should be shared.

QUESTIONS AND DISCUSSION

1. The prospect of geoengineering raises unique and difficult institutional challenges for the international system. No organization is tasked with taking an integrated look and managing the unintended consequences of something as substantial as the geoengineering proposals being discussed. What do you think may be the legal implications of these geoengineering proposals? What type of regulatory or governance regime would you recommend, before allowing such geoengineering proposals to proceed? Should there be liability for any unintended consequences? Does environmental assurance bonding provide a useful strategy for addressing the impacts of geoengineering?

2. The relative feasibility and low cost of aerosol scattering also raise specific types of issues. Either large private sector actors or individual governments could afford to finance aerosol scattering on their own. What would happen if the climate impact on Russia's far north became too acute? What would stop Russia from unilaterally deciding to launch aerosols into the atmosphere? What kind of governance structure would you want in place? Do you think we have the international laws and institutions in place to prevent or restrict countries from undertaking geoengineering activities? What types of restrictions would you like to see? Does Scott Barrett's proposal offer a solution?

3. The Kyoto Protocol contemplates providing credit for at least some sequestration efforts. Net changes in a country's emissions under the regime include any changes due to the enhancement of sinks, although this is currently limited to changes in land-use and forest projects. Similarly, credits for sinks under the Clean Development Mechanism (CDM) are limited to land-use and forest-related projects. Thus, proponents of ocean fertilization will likely require some changes in the current regime to receive carbon credits under the climate regime. Before such changes are made, significant technical issues regarding measurement and verification of emissions reductions will need to be resolved. Given the climate regime's current broad approach to sinks and given the effort that continues to go into measuring and verifying carbon sequestration, the technical issues for ocean fertilization may not be insurmountable.

Certainly, the private sector firms believe ocean fertilization has a commercial future, considering how the climate regime treats sequestration from forest activities. *See* Chapter 8.

4. Geoengineering proposals aimed at screening the sun (or shading the earth) would arguably be a form of environmental modification covered by the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, signed May 18, 1977, *reprinted in* 16 I.L.M. 88 (Jan. 1977) [hereinafter ENMOD Convention]. The primary purpose of the ENMOD Convention is to prohibit military or hostile use of such techniques, but in so doing it clearly contemplates their peaceful use. Indeed, the ENMOD Convention states that Parties "shall not hinder the use of environmental modification techniques for peaceful purposes. . . . " The Convention clearly makes environmental modification techniques a focus of international law and may implicitly at least be viewed as prohibiting the unilateral use of environmental modification techniques. In this regard, Parties to the Convention "undertake to facilitate, and have the right to participate in, the fullest possible exchange of scientific and technological information on the use of environmental modification techniques for peaceful purposes."

5. Geoengineering proposals that assume specific use of outer space may also fall under the Outer Space Conventions. *See* Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, done January 27, 1967, 610 U.N.T.S. 205(1967), *reprinted in* 6 I.L.M. 386 (1967); Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, done Dec. 5, 1979. Under these treaties, outer space is the common heritage of humankind and must be managed for peaceful purposes for the benefit of all humanity. Scientific studies of space must avoid adverse environmental impacts on Earth, and any State is internationally liable for any damage caused by articles launched from their territory. How could geoengineering proposals lead to claims of damage on Earth? Would States participating in geoengineering to change the climate be more susceptible to liability claims than States that have changed the climate indirectly through burning fossil fuels?

6. Lawyers find it difficult to talk about "managing the planet" because we know how inadequate our legal institutions are for effective, democratic, and fair planetary management. But the technical manipulation of the planet is becoming more realistic. Climate change, itself, is essentially accidental geoengineering, and now the question is whether we need to *intentionally* re-engineer the climate to manage our way out of the mess. If scientists tell us it is technologically and economically feasible to geoengineer the planet, then should we not also evaluate our institutional and legal structures to determine whether they are able to manage such geoengineering? Or should ethical considerations prevent us from going down the geoengineering path? Is such manipulation of the planet more like building a dam to control river flows, which we consider open to reasonable debate, or more like human cloning, which we have essentially prohibited as spiritually and ethically suspect?