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By Robert H. Socolow[*]

I. INTRODUCTION

In 1958, Charles David Keeling began measuring the concentration of carbon dioxide (CO_2) in the atmosphere, at a site 11,000 feet above sea level near the top of Mauna Loa on the "big island" of Hawaii. The time series of monthly averages, the "Keeling Curve," is the iconic figure of climate change (see Figure 1). The curve oscillates and rises. The annual oscillations (whose details are seen in the Figure's inset) are the consequences of the seasonal breathing of the northern-hemisphere forests, which remove CO_2 from the atmosphere during their growing season and return CO_2 to the atmosphere as their leaves decay on the forest floor in winter. The steady rise—on average today, about 0.5% per year—is due primarily

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to the burning of fossil fuels. Indeed, the average rise would be twice as fast if all of the CO_2 released during fossil-fuel burning stayed in the atmosphere. Roughly half of the CO_2 emissions from burning fossil fuels stay in the atmosphere, one quarter go into the ocean (making it more acidic), and one quarter enter forests that, despite deforestation, are growing bigger.[1]

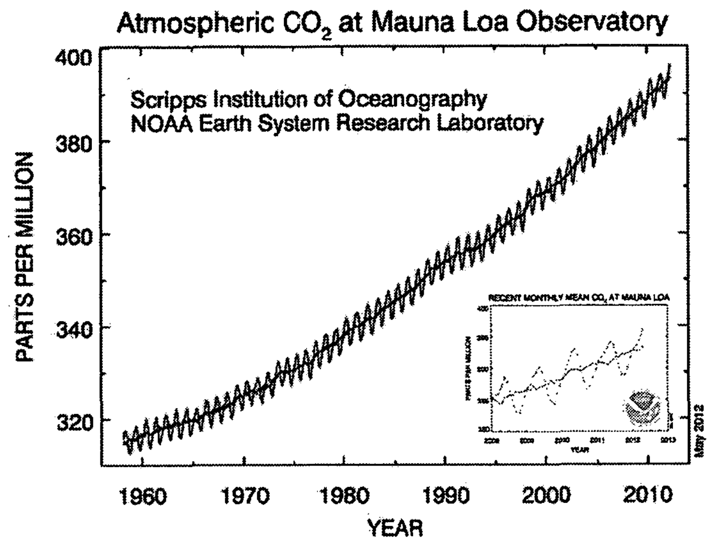

Figure 1: Monthly average CO_2 concentration at the Mauna Loa Observatory, 1958 through April 2012. The vertical scales are number of CO_2 molecules per million molecules of atmosphere (left) and billions of tons of CO_2 ($GtCO_2$) in the atmosphere (right, author's addition).[2]

The era of consciousness of climate change began with Keeling's intrepid measurements.[3] The seasonal oscillations in Figure 1 were unexpected, and it was soon clear that atmospheric CO_2 measurements were a new index of global human impact. The political message was that the global atmosphere mixes and retains a large part of the world's CO_2 emissions, oblivious to what fuel is burned, in what country, and for what purpose. Again and again over the past fifty years, modelers have estimated future human emissions on the

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1. The reader interested in delving further into climate science can read or browse the IPCC Fourth Assessment Report: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS (SUSAN SOLOMON ET AL. EDS., 2007), *available at* http://ipcc.ch/publications_and_data/ar4/wg1/en/contents.html. Of particular interest is the "Frequently Asked Questions" section.

2. *Trends in Carbon Dioxide*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. http://www.esrl.noaa.gov/gmd/ccgg/trends/ (last visited Nov. 6, 2012).

3. Charles D. Keeling, *Rewards and Penalties of Monitoring the Earth*, 23 ANN. REV. ENERGY & ENV'T 25 (1998).

basis of assumptions about the economy and technology, while environmental scientists have gradually improved their ability to describe the likely consequences for global warming, sea-level rise, ecosystem disturbance, and hydrocycle disruption (storms, floods, droughts, etc.).

The landmark international treaty, the United Nations Framework Convention on Climate Change ("UNFCCC"), is often called the Rio Convention, because it was negotiated in Rio de Janeiro at the "Earth Summit" in June of 1992. As can be discerned from Figure 2, the rate of fossil fuel emissions almost tripled between 1958 and 1992 (from 8.5 to 22.7 billion tons of CO_2 per year, an average increase of 2.9% per year for thirty-four years). By 2010, it had increased by another 40% (to 33.5 billion tons of CO_2 per year, an average increase of 2.2% per year for eighteen years) and was four times larger than in 1958.[4]

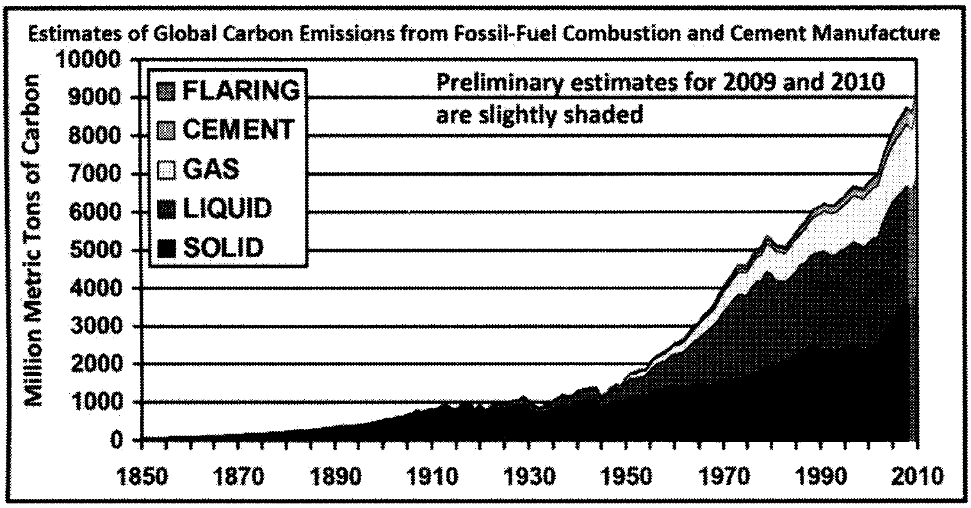

Figure 2: Annual emissions of CO_2, 1850–2010, from fossil fuels, cement, and the flaring of gas at oil fields. (Flaring is barely visible, and occurred only in the 1970s.) The vertical scale displays *annual* emissions. Note that the unit is million metric tons of *carbon, not CO_2*. To convert to million metric tons of CO_2, multiply by 3.667. The 2009 and 2010 data are "preliminary."[5]

4. *Estimates of Global Emissions from Fossil-Fuel Combustion and Cement Manufacture*, CARBON DIOXIDE INFO. ANALYSIS CTR., http://cdiac.ornl.gov/images/preliminary_2009_2010_fossil_carbon_emissions.jpg (last visited Sept. 29, 2012).

5. *Global CO2 Emissions From Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2008*, CARBON DIOXIDE INFO. ANALYSIS CENTER (June 10, 2011), http://cdiac.ornl.gov/ftp/ndp030/global.1751_2008.ems.

I write soon after returning from "Rio + 20," a blockbuster United Nations event in June 2012 celebrating the twentieth anniversary of the Rio Convention. The mood in Rio was sober. United Nations diplomacy appeared to be shutting down. Judging from political rhetoric, discussion of climate change in the United States has already shut down. A premise of this Essay is that the current impasse has little social value. This Essay is about finding "restart buttons."

I am addressing "the environmental community," by which I mean all those who engage with environmental issues, notably climate change, whether professionally or simply because they find the issues compelling. The environmental community extends well beyond the environmental activist community and the environmental non-governmental organizations. My assumption is that nearly all members of the environmental community, independent of where they stand on particular issues, feel frustrated by the current incoherent state of affairs and the lack of progress. The environmental community definitely includes me, which is why, below, I frequently refer to this community as "we." Only in the final section of this Essay do I use "we" to refer to all of humanity.

In my view, the environmental community does not need to wait for economic recovery or political reform or the withering away of disinformation campaigns. The central argument of this Essay is that we will find "restart buttons" when we become better at telling truths to ourselves.

II. COMMUNICATING CLIMATE CHANGE

There are two novel ways by which the environmental community, in its role as messenger of climate change, could tell the story with greater empathy and candor. We could acknowledge that (1) climate change is unwelcome news, and (2) the best and worst outcomes consistent with today's climate change science are very different.[6]

Climate change is unwelcome news. Never in history has the work of so few led to so much being asked of so many. The few are the climate scientists. They have developed a solid case that increases in CO_2 emissions threaten our well-being. The many are the rest of

6. A previous exploration of these issues can be found in Robert Socolow, *Wedges Reaffirmed*, CLIMATE CENT. (Sept. 27, 2011), http://www.climatecentral.org/blogs/wedges-reaffirmed/.

humanity. Everyone would rather live on a bigger planet—a planet, say, as large as Jupiter—where our day-to-day activities mattered far less. On *our* planet, however, the insights from climate science reveal that humankind is a powerful agent of undesired change.

The natural reaction of anyone hearing unwelcome news is to shoot the messenger. Scientists brought such profoundly unwelcome news twice before. In 1610, Galileo pointed his telescope to the night sky, saw the phases of Venus and the moons of Jupiter, and published his observations in *Starry Messenger*. The English poet John Donne realized immediately that here was compelling evidence that the earth was not at the center of the universe, and that this news would be devastating to established political and social hierarchies. He wrote, only months later, in *The First Anniversary*:

> And new philosophy calls all in doubt,
> The element of fire is quite put out;
> The sun is lost, and th'earth, and no man's wit
> Can well direct him where to look for it . . .
> 'Tis all in pieces, all coherence gone,
> All just supply, and all relation;
> Prince, subject, father, son, are things forgot,
> For every man alone thinks he hath got
> To be a phoenix, and that there can be
> None of that kind, of which he is, but he.
> This is the world's condition now.

Galileo, the messenger, was not actually shot, but in 1633 the Inquisition in Rome found him "vehemently suspect of heresy," and he was required to "abjure, curse, and detest" the Copernican theory. Galileo was confined to his home for the remaining eight and a half years of his life.[7]

Two and a half centuries after *Starry Messenger*, Charles Darwin published *The Origin of Species*. Darwin argued that human beings were part of the animal kingdom, another decidedly unwelcome idea. Although held in high esteem by his colleagues, he was mocked in the popular press, and his findings are still widely dismissed.

Thus, no one should be surprised at the fierce resistance to climate-change science, nor should anyone expect that resistance to crumble quickly. The idea that humans cannot change our planet is as

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7. DAVID WOOTTON, GALILEO: WATCHER OF THE SKIES 5 (2010).

out-of-date and wrong as the earth-centered universe and the separate creation of man. But all three ideas have such appeal that they fade away only very slowly.

The best and worst outcomes consistent with today's climate change science are very different. Neither slow nor rapid arrival of severe climate change can be ruled out, given our poor understanding of the many ways by which the earth's atmosphere, oceans, ice, and forests can amplify or dampen what are initially relatively small disturbances, arising from the earth's not quite circular orbit around the sun. The earth is a physical system with many complex positive and negative feedbacks. This key message from climate science is not what most nonscientists read or hear, because the media, politicians, and environmentalists—and sometimes the climate scientists themselves[8]—prefer to describe a simpler world with distinct zones of safety and peril. The working assumption of nearly all communicators is that the general audience requires simplification, and that, in particular, the public cannot comprehend risk.

My problem with this working assumption is that it is belied by how people, every day, incorporate information about an uncertain outcome and act to reduce its consequences. Well aware that they do not know if there is a patrol car around the next bend in the road, drivers still usually drive slowly enough to avoid getting a ticket for speeding. At a far different scale, people reduce the consequences of uncertain outcomes by buying fire insurance and life insurance, and they reduce the probability of these same outcomes by replacing the frayed insulation on electric wires in their homes and eating healthily. Why should various lay audiences be unable to process and act on the information that no one knows how soon our actions on this planet will bring on dangerous climate change, nor exactly what "dangerous" means, because climate change science is seriously incomplete?

My ecologist colleague, Steve Pacala, explains to lay audiences that "there are monsters behind the door." Scientists do not know how strong the door is. They do not know how quickly the Greenland and West Antarctic ice sheets will melt, nor whether the near future will bring significant greenhouse gas releases from the arctic tundra and more intense hurricanes. A public convinced that our collective future could bring an array of menacing risks—and accepting that current knowledge of these risks is incomplete—may endorse forceful actions

8. I explore how climate scientists communicate uncertainty about extreme events in Robert H. Socolow, *High-Consequence Outcomes and Internal Disagreements: Tell Us More, Please*, 108 CLIMATIC CHANGE 775 (2011).

by its leaders to reduce those risks. Might talking straight instead of second-guessing the audience be a "restart button"?

In the remainder of this Essay, with an emphasis on finding ways to freshen the conversation, I will address energy demand and supply and international politics.

III. DEMAND

If you look at a map of the national highway system in the United States (Figure 3), it becomes a Rorschach test. The mind can go in many directions. It may go to the extraordinary political and technological achievement of building and operating the system, to the connectedness of the country, to the opportunities for travel and tourism, or to urban sprawl and the changing nature of land use. We in the environmental community see vehicle fuel, the global oil market, and CO_2 emissions. Vehicles (cars, trucks, planes, and ships) are responsible for nearly all of the consumption of petroleum not associated with petrochemicals and for about 30% of national CO_2 emissions.[9]

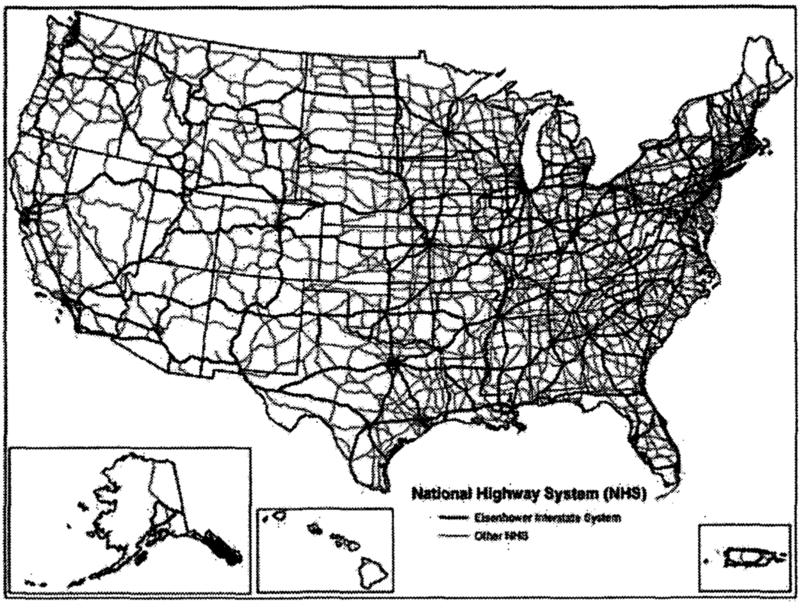

Figure 3: The U.S. national highway system.[10]

9. U.S. ENERGY INFO. ADMIN., ANNUAL ENERGY OUTLOOK 2012 WITH PROJECTIONS TO 2035, at 76 fig.72 (2012), *available at* http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf.

10. File: National Highway System.jpg, WIKIPEDIA (July 18, 2005), http://en.wikipedia.org /wiki/File:National_Highway_System.jpg.

Figure 4 is the equivalent of Figure 3 for electricity. In the United States, the past half century saw the building of power plants contemporaneously with the building of the highway system. Power plants are responsible for about 40% of national CO_2 emissions: roughly 30% from coal plants and 10% from natural gas plants. To understand power plants in terms of energy demand, one needs to know that 70% of U.S. electricity is consumed in buildings—for lighting, cooling and heating systems, appliances and electronics—and about equally in residential and commercial buildings.[11] Often, the most cost-effective societal alternative to any kind of power plant is no power plant at all, but, rather, an economy-wide investment in better appliances and air conditioning systems.

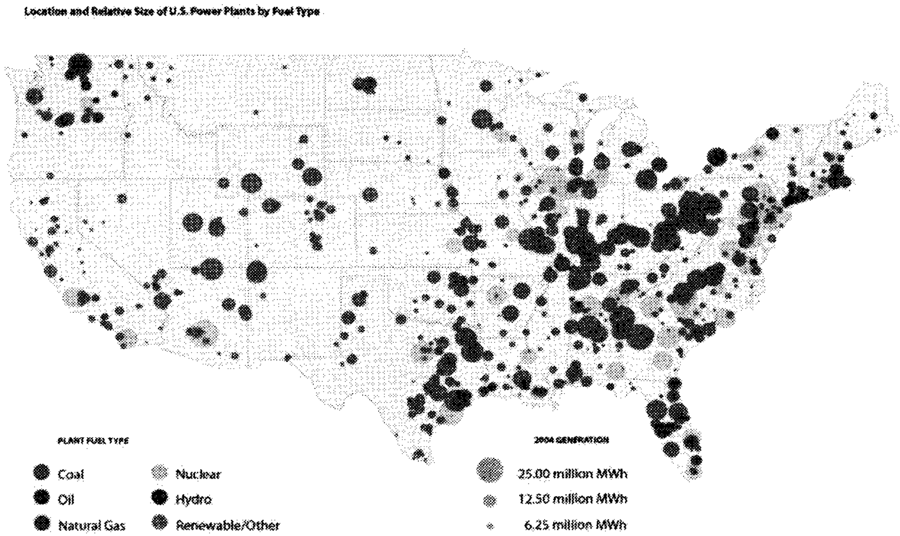

Figure 4: Power plants in the United States.[12]

Individual emissions. Rarely today are consumers aware of how their various demands for energy create their carbon footprints. One way I like to convey this information is to connect the CO_2 emissions from specific activities to the globally averaged annual per-capita emissions from the burning of fossil fuels, currently about four tons of CO_2 per year (30 billion tons of CO_2 per year, divided by 7 billion people). Each of several activities, by itself, gets the American

11. *Id.*

12. SANDRA GOODMAN & MICHAEL WALKER, E[3] VENTURES, BENCHMARKING AIR EMISSIONS 8 fig.3 (2006), *available at* http://www.nrdc.org/air/pollution/benchmarking/2004/benchmark2004.pdf.

all of his or her four-ton-per-year global share. Take vehicle use: if you drive 15,000 miles per year (which many of us do) in a car averaging forty-five miles per gallon (which most of us do not have), your car emits four tons of CO_2 per year. If you drive a car that gets twenty-two miles per gallon, you reach your global share after driving only 8,000 miles. You also use up your global share by flying 15,000 miles per year on commercial passenger aircraft—economy class. (Your emissions are the plane's emissions divided by the number of people in the plane—taking into account the space required for economy-class vs. business-class seats.) If you heat your home with natural gas in an average temperate climate like Princeton, New Jersey, where I live, that will approximately use up your global share, too, if you live alone. Electricity usage is more complicated because the carbon intensity of your local electricity matters: 300 kilowatt-hours a month will use up your global share when all the power comes from coal. Given the number of ways that an American can emit as much CO_2 as the world's average person, it is hardly surprising that the average American emits five times the global average, about twenty tons per year.

Technology can help reduce the CO_2 emissions from buildings and vehicles, but recent history shows its limitations. Since the early 1970s, researchers, industry leaders, and policymakers have collaborated to create regulations that make buildings, appliances, and vehicles more efficient. But these efforts have been countered by bigger homes, additional appliances, peppier vehicles, and more extensive travel. Evidently, along with energy efficiency, people value much else. They value privacy, independence, safety, comfort, beauty, and a variety of experiences. Yet "bottom up" projections of future CO_2 emissions and emissions-reduction potential for homes and vehicles rarely recognize these desires explicitly. How refreshing it would be to see web-based carbon-footprint software for calculating an individual's carbon footprint that not only probes an individual's specific consumption patterns but also the values that drive this consumption. Might more open discussion of modern lifestyles be another "restart button"?[13]

Project evaluation. Countless projects have as one of their goals CO_2 emissions reduction relative to some standard. Whether

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13. A good entry into the literature about energy use and behavior is Thomas Dietz, Gerald T. Gardner, Jonathan Gilligan, Paul C. Stern & Michael P. Vandenbergh, *Household Actions Can Provide a Behavioral Wedge to Rapidly Reduce US Carbon Emissions*, 106 PROC. NAT'L ACAD. SCI. 18452 (2009).

outcomes match intentions can only be discovered through measurement and analysis. In the words of Ronald Reagan, "trust but verify." Easier said than done. Both public and private institutions are almost guaranteed to resist verification, believing that they have more to lose than to gain by finding out how well their projects have performed.

A case in point is the Leadership in Energy and Environmental Design ("LEED") rating system (certified, silver, gold, platinum) managed by the U.S. Green Buildings Council. Over the past two decades, LEED has effectively raised awareness of the extent to which a building design determines energy use. One reason LEED is a popular institutional invention is that the building is rated entirely at the design stage; the rating is not affected by what happens during construction or after the building is built. There is a missed opportunity here. One can hope that those responsible for the LEED rating system will soon incorporate a learning process among building professions that promotes the integration of design, construction, commissioning, and operation.

Population. The size of the world's population is another complex subject that the environmental community has been avoiding. In the 1970s, by contrast, population and environment were joined at the hip. A popular textbook of the time by Paul and Anne Ehrlich and John Holdren carried the title: *Ecoscience: Population, Resources, Environment.* The story of why and when the environmental community jettisoned population from its domain of direct concern is, thus far, untold. Population must reenter the conversation. I often say to my students, "You may be participating in recycling programs or planning to make your first car a hybrid, but the decision you will make in your life with the most impact on natural resources and sustainability is how many children to have." In response, I get a blank stare; forty years ago there would not have been blank stares.

The actual future population will have an enormous impact on the quality of life on this planet, and it is far from determined. The United Nations brackets the global population in 2100 by a "high" value of 15.8 billion and a "low" value of 6.2 billion[14] (see Figure 5). The high and low estimates result when the average woman has 2.6 and 1.6 children, respectively. Just one extra child, and the result is nearly 10 billion extra people!

14. U.N. DEP'T OF ECON. & SOC. AFFAIRS, WORLD POPULATION PROSPECTS: THE 2010 REVISION, HIGHLIGHTS AND ADVANCE TABLES, at xv (2011), *available at* http://esa.un.org/unpd/wpp/Documentation/pdf/WPP2010_Highlights.pdf.

The perils of the UN's "high" scenario, where by 2100 the global population more than doubles, relative to today, are many. Assuming that the world continues to find paths to sustained economic growth, the environmental pressures on the atmosphere, the food system, and biodiversity will be immense—as will be the crowding in public spaces, in commercial airspace, and on the roads.

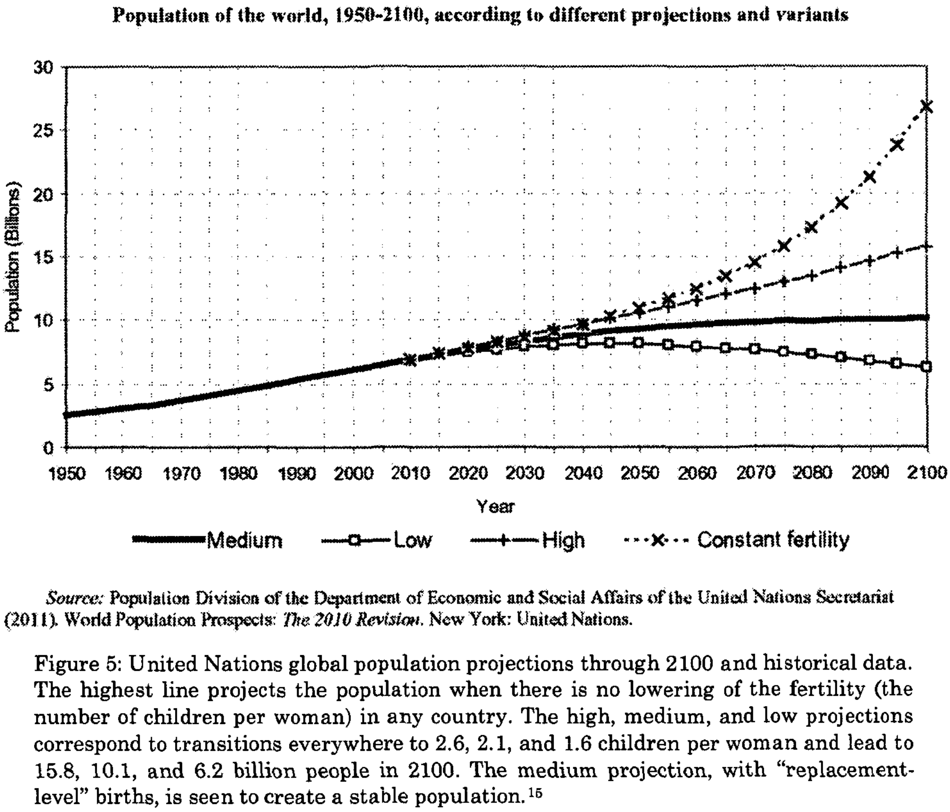

Figure 5: United Nations global population projections through 2100 and historical data. The highest line projects the population when there is no lowering of the fertility (the number of children per woman) in any country. The high, medium, and low projections correspond to transitions everywhere to 2.6, 2.1, and 1.6 children per woman and lead to 15.8, 10.1, and 6.2 billion people in 2100. The medium projection, with "replacement-level" births, is seen to create a stable population.[15]

Under the low projection, the global population peaks around 2050 at approximately 8 billion people. By 2100, it is falling at the rate of 0.8% per year.[16] A continued fall in the global population at the

15. U.N. DEP'T OF ECON. & SOC. AFFAIRS, WORLD POPULATION PROSPECTS: THE 2010 REVISION, HIGHLIGHTS AND ADVANCE TABLES, at xvi fig.1 (2011), *available at* http://esa.un.org/unpd/wpp/Documentation/pdf/WPP2010_Highlights.pdf.

16. For the United Nations "low" trajectory, the world population is 6,228 million in 2099 and 6,177 in 2100,' a growth rate of -0.82%. U.N. DEP'T OF ECON. & SOC. AFFAIRS, WORLD POPULATION PROSPECTS: THE 2010 REVISION (2011), http://esa.un.org/unpd/wpp/Excel-Data/population.htm (follow "Total Population-Both Sexes" hyperlink; then select the "Low" tab in the associated spreadsheet).

rate of 0.8% per year throughout the twenty-second century would lead to fewer than 3 billion people by 2200—without war or pestilence. The world population was below 3 billion people until 1960.[17]

One reason the environmental community has disengaged from the subject of population growth is that the problem simply is not as dire as it was. Great strides have been taken in the past few years in most parts of the world toward smaller families. In addition, problematic features of the transition to a *level* population are becoming better appreciated, notably the aging of the population. The increase in the fraction of older people and the decrease in the fraction of children will preoccupy nearly every country through much of the twenty-first century. The "medium" UN scenario predicts almost 800 million people above the age of eighty in 2100—roughly 8% of the global population.[18]

The environmental community could reconnect with population issues by challenging national policies that reward parents for large families—so-called "pro-natalist" policies, now in place or under discussion in many of the industrialized countries where populations are actually shrinking or are on track to decline. Issues such as cultural survival (in what year will the last Italian be born?) would need to be joined. The population issue is about more than population growth in the developing world.

IV. SUPPLY

There are further examples of the environmental community not quite telling itself the truth in the domain of energy supply. For starters, although we, like much of the U.S. public, are fascinated with new ways of producing energy, the story of carbon in the United States is above all a story about old coal power plants. Built primarily in the sixties, seventies, and eighties, coal power plants are outdated and inefficient bastions of CO_2 emissions (as well as emissions of air pollutants having direct impact on public health). Owners of coal plants expend most of their political capital ensuring that current plants are allowed to keep running because the capital that was required to build them is largely paid off and the profits are large. Politicians in coal-power states work to preserve the competitive advantage of low-cost power. Grandfathering, retiring, relicensing,

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17. JOEL E. COHEN, HOW MANY PEOPLE CAN THE EARTH SUPPORT? 401 (1995). Cohen's book is an excellent reference for population-environment linkages.

18. U.N. DEP'T OF ECON. & SOC. AFFAIRS, *supra* note 10, at xvi.

repowering, and retrofitting: resolving these contentious issues provides immense leverage for any long-industrialized nation wishing to reduce its CO_2 emissions. By contrast, these are not the dominant issues for a now-industrializing nation like China, where most of the electricity comes from power plants built in the last decade.

The many factions who participate in the formulation of low-carbon energy policy argue heatedly with one another. Advocates of nuclear power and advocates of renewable energy rarely join forces. In this domain, self-deception extends well beyond the environmental community. It takes the form of believing that alternatives to your favorite option are not worth taking seriously. In my view, if you are an advocate of any low-carbon energy technology, you will be much better prepared for the fray if you assume that the technologies you most dislike are going to be strong competitors. For every option that you dislike, focus your attention on "conditionality." Every option can be done badly or well. Under what circumstances could you accept the deployment of one of the alternatives you do not like, as a companion to the deployment of one you do like? The reason your attention to conditionality is so important is that every nominal "solution" to climate change has a dark side, and proponents of that solution are not the ones who can be counted on to identify what can go wrong.[19]

In what follows, I briefly discuss how conditionality might affect four specific technological options for managing climate change—CO_2 capture and storage ("CCS"), biocarbon, nuclear power, and geoengineering.

CO_2 *capture and storage.* The debate over CCS within the environmental community today is both polarized and consequential. There are two views. One view sees coal, oil, and natural gas as energy sources on their way out, giving way to a new world of renewable energy (alternatively, although rarely, to a new world of nuclear energy). From this perspective, new fossil fuel power—and especially new coal power—is out of step with the march of progress. The opposing view (which I hold) sees fossil energy as a fierce competitor indefinitely. Specifically, this view welcomes technologies that enable new kinds of coal and natural gas power plants with greatly reduced CO_2 emissions, which CCS power appears poised to deliver.

19. I first made the case for parallel efforts to address climate change in two papers with Stephen Pacala. *See* S. Pacala & R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 SCIENCE 968 (2004); Robert H. Socolow & Stephen W. Pacala, *A Plan to Keep Carbon in Check*, SCI. AM., Sept. 2006, at 50.

Whether at a new or retrofitted power plant, and whether the fuel source is coal or natural gas, CCS requires that a potential emitter of CO_2 instead traps and redirects nearly all of the CO_2 produced during burning so that it never enters the atmosphere. The most studied destination is the porous geologic formation deep underground. A power plant that captures CO_2 is considerably more expensive than one that does not, and storage creates additional costs. Electricity from CCS plants can become competitive with conventional power plants only in regional power markets that have imposed a significant (direct or indirect) price on CO_2 emissions. In some cases, the power plant owner can reduce the cost penalty by selling captured CO_2 to owners of depleted oil fields, who can use the CO_2 for "enhanced oil recovery" (which high oil prices promote), while storing the CO_2 in the process. A regional energy system containing hundreds of CCS facilities linked by an extensive CO_2 pipeline infrastructure is worth detailed examination.

Today's discussion of CCS within the environmental community rarely gets to this stage. Rather, especially in Europe and especially regarding coal, those who drive the discussion of climate change mitigation rule out CCS-enabling policies on the grounds that they facilitate the continuation of the fossil fuel era. Hardly anyone hostile to coal asks whether there is a level of performance in the coal industry—in mine-worker safety, management of acid runoff, land restoration, air pollution control, or other domains where the coal industry has earned the hostility it now faces—that is good enough to warrant accepting coal's long-term contributions to the energy system. If such questions were asked, perhaps a middle ground could be reached, where all new coal power is CCS power. Absent such efforts, coal power without CCS will probably prevail, and CO_2 emissions associated with coal power will experience little downward pressure.

Biocarbon. "Biocarbon," in the context of this Essay, encompasses all the ways in which biological strategies could slow climate change. There are stock strategies and flow strategies. Stock strategies transfer the carbon in the atmosphere (where the carbon is present almost exclusively as CO_2) to another "carbon reservoir," such as a forest; planting a tree, for example, will result in carbon moving from the atmosphere to the tree while the tree grows. Restoring previously forested land (afforestation) is an example of a stock strategy. Flow strategies exploit the substitutability of biological energy for fossil energy: to keep warm one can burn either wood or coal in a furnace. A successful modern biomass industry, whether based on forest residues or dedicated crops like sugar cane, will delay climate change by allowing some petroleum to stay below ground.

Stock strategies and flow strategies compete for land with each other and with the demands of agriculture, animal husbandry, timber, paper, parks, and wilderness. Conditionality for biocarbon strategies means ensuring that other functions of land are not overwhelmed—that biomass expansion does not divert land from agriculture nor lead to the clearing of forests. Imagine that you are a forester or agronomist fostering some biocarbon initiative that has no associated conditionality. Your focus will be on storing as much carbon or growing as much biofuel as possible, and your plan may run roughshod over other land-use objectives. Good policy design will require getting into the heads of foresters and agronomists and creating the incentives and penalties that will lead them to fulfill the multiplicity of objectives that must govern the management of increasingly scarce land.

Nuclear power. To become a major contributor in this half-century, nuclear power would need to expand rapidly across the world, by a factor of three to five globally, relative to today.[20] Much on the minds of all those who struggle with nuclear power's potential are conditionalities related to power plant safety (especially after Fukushima) and nuclear waste disposal (which, with few exceptions, is not yet solved anywhere). But there is an additional conditionality, one that in my view is even more important: a precondition for a global expansion of nuclear power is the creation of much higher barriers between nuclear power and nuclear weapons than now exist. Today, as the falling cost of uranium enrichment and the legitimation of commercial plutonium lower these barriers, some nuclear power advocates are at last acknowledging these links.[21] With weapons couplings at the front of our minds, Alex Glaser and I recently wrote, "[W]e judge the hazard of aggressively pursuing a global expansion of nuclear power today to be worse than the hazard of slowing the attack on climate change by whatever increment such caution entails."[22] Nuclear power expansion does not need to be so fatefully linked with the prospect of nuclear war. One constructive step would be to manage international civilian uranium and plutonium in ways that reduce the risks of regional nuclear arms races. Barriers would be introduced to restrict the production of weapons-usable materials and their

20. Robert H. Socolow & Alexander Glaser, *Balancing Risks: Nuclear Energy & Climate Change*, DAEDALUS, Fall 2009, at 31, 32–33.

21. Anne Lauvergeon, *The Nuclear Renaissance: An Opportunity to Enhance the Culture of Nonproliferation*, DAEDALUS, Fall 2009, at 91. At the time, Lauvergeon was the Chief Executive Officer of AREVA.

22. Socolow & Glaser, *supra* note 15, at 41.

diversion to national military programs. However, no country is currently willing even to discuss the minimal sacrifices of sovereignty that would be required. Even worse, more countries are finding nuclear weapons attractive. This can only increase the proliferation-related risks of a global expansion of nuclear power.

Geoengineering. Advocates of geoengineering think about conditionality, even though most of the public knows very little about what geoengineering might entail. Anticipating a contentious debate, the advocates are getting out in front, asking themselves what constraints they would want to put on research, deployment, evaluation, and governance. They are encouraging the early arrival of ground rules.

Geoengineering, in its most discussed manifestation, would involve deliberately decreasing incoming sunlight to counteract the warming from greenhouse gases. Today's earth reflects about 31% of incoming sunlight to space; especially good reflectors are cloud tops and ice, but every surface struck by sunlight contributes. Sunlight that is reflected does not warm. Modifying the planet to reflect an additional 1% (so that a total of 32% is reflected) would cool the earth's surface by roughly as much as greenhouse gases in the atmosphere will have warmed the surface from the onset of the Industrial Revolution to the middle of this century.[23] One way to increase our planet's reflectivity is to imitate the most powerful of past volcanic eruptions. These eruptions create stretches of unusually cool weather globally for a year or more by sending millions of tons of sulfur oxides into the stratosphere where they form long-lasting reflective particles. Human beings could loft particles into the stratosphere with rockets or guns or balloons.

Conceding the limitations of current climate science, one should be wary of a climate strategy based on the perpetual replication of artificial volcanoes. Nonetheless, given that (as noted earlier) the rate at which humanity will confront nasty manifestations of climate change is uncertain, geoengineering might be a welcome option some decades from now. It will not be available as an option,

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23. An increase from 31% to 32% in the fraction reflected would reduce the rate of solar warming by between three and four watts per square meter of surface area of the earth. This is sufficient to compensate, approximately, for an increase in warming due to a doubling of greenhouse gases in the atmosphere relative to preindustrial times, a situation that will be reached at mid-century in the absence of serious action to reduce greenhouse gas emissions. *See* THE ROYAL SOCIETY, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY 24 (2009), *available at* http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/8693.pdf. For a full discussion, see *id.* at 23–36.

however, unless efforts begin now to improve scientific understanding of how such schemes might be implemented and their associated environmental risks.

There is a large overlap between the areas of climate science that are priorities for climate research and those receiving greatest attention in geoengineering discussions—notable areas are clouds and aerosols. Yet, at present, the leadership of the climate research community sees more peril than gain in acknowledging—much less promoting—this overlap. Geoengineering today carries a stigma. Geoengineering is unlikely to progress until there is broad discussion of what so many people find so troublesome about it.

Thus far, geoengineering has received scrutiny only from scientists, engineers, and a few philosophers. As the general public and its representatives become aware of geoengineering, they are likely to insist that the desirability of geoengineering under *any* circumstances be debated before conditionality is addressed. Important aspects of the relationship between human beings and the larger natural world are transformed fundamentally on a geoengineered planet. In a debate on geoengineering, one can anticipate, for example, that some will argue for preserving randomness and surprise.[24] A debate over such basic principles is needed, but it is not yet in view.

To be consistent, those of us who frame climate change as risk management must promote not only more ambitious climate science, but also an early beginning for geoengineering research. Thus, the way forward would seem to require, first, a broad debate that engages, on the one hand, the deep religious structure of the offer that geoengineering is presenting to humanity and, on the other hand, the worst-case prospects for climate change that are currently consistent with climate science. I anticipate that a consensus will emerge—in a few places, but not everywhere—that a geoengineering research program would be prudent. Where this consensus emerges, climate science could be reimagined and reconfigured so as to encompass geoengineering research as a significant but subordinate enterprise. The need to understand more deeply how the earth works would still dominate.

The more the world fears climate change, the less those of us who concern ourselves with slowing its arrival can allow ourselves to

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24. Similar arguments are found in related debates about the problematic outcomes of genetic engineering. *See* MICHAEL J. SANDEL, THE CASE AGAINST PERFECTION: ETHICS IN THE AGE OF GENETIC ENGINEERING (2007).

be squeamish about imperfect solutions. We must remind ourselves that we want solutions to work. It cannot be enough for us to identify what is wrong with a strategy as it is first proposed. We must ask ourselves: What changes would be required for the strategy to become acceptable? How might the world get from here to there? After due consideration, in some cases, we may conclude that this is an option we cannot recommend. In most cases, this will be tantamount to recommending that some alternative options be scaled up. But in cases where every other strategy has reached some state of maximum deployment, in effect we would be recommending that the world endure some incremental damage from climate change rather than make the compromises required to prevent it.

In short, climate change is a problem of risk management. It requires balancing the risks of disruption from climate change and the risks of disruption from mitigation. Humanity can do too much or too little. To give Hippocrates the last word, "I will apply, for the benefit of the sick, all measures that are required, avoiding those twin traps of overtreatment and therapeutic nihilism."[25]

V. INTERNATIONAL CONSIDERATIONS

CO_2 emissions continue to rise rapidly in many developing countries, while across most of the industrialized world emissions appear to have peaked. Defining the industrialized world as the members of the Organization for Economic Cooperation and Development ("OECD"), about 40% of global emissions from burning fossil fuels now originate from their territories, and that fraction is falling.[26] Ultimately, the developing world will decide what kind of planet earth becomes. If, on balance, most of the larger developing countries judge that the slowing of climate change is an urgent matter, they will drive the world toward a low-carbon economy. If, however, they decide that adapting to climate change has higher priority than reducing its severity, investments in resilience will dominate investments in so-called "clean tech," and global CO_2 emissions may rise throughout this century. Only for a few more decades will the major industrialized countries be able to lead by example and persuasion.

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25. Louis Lasagna, *Hippocratic Oath: Modern Version* (1964).

26. In 2009, OECD emissions were 12.0 billion out of a global total of 29.0 billion tons of CO_2. *See* ORG. FOR ECON. COOPERATION & DEV., OECD FACTBOOK 2011-12: ECONOMIC, ENVIRONMENTAL, AND SOCIAL STATISTICS 200–01 (2011), *available at* http://dx.doi.org/10.1787/factbook-2011-78-en.

Historically, the UNFCCC put the burden of addressing climate change exclusively on developed countries, while excusing the developing world. The operative phrase in the 1992 Rio Convention, "common but differentiated responsibilities," inhibited global planning. Such a two-tier world fits a "post-colonial" mindset: it aligns guilt in the developed world with entitlement in the developing world. Long overdue in my view, developing and industrialized countries in recent years have begun to acknowledge that all of humanity is in the same boat. The world is at last inventing "post-post-colonial" institutions.

Beyond per capita emissions. In a post-post-colonial world, leaders will concede that most of the emissions in developing countries arise not from billions of very poor people but from individuals with consumption patterns mirroring their middle-class and upper-class equivalents in industrialized countries. Right now, this reality is well disguised in arenas like the United Nations because discussion only of national per capita data is allowed. Indeed, in aggregate, non-OECD per capita emissions are three to four times smaller than those of the OECD, and many developing countries have hardly started on the path toward industrialization. But five-sixths of the world's population lives outside the OECD and produces 60% of global emissions. It has become critical to think about emissions in a different way.

I wrote a paper with several colleagues in 2009 that addressed this issue.[27] Using World Bank income distributions and total national carbon emissions, and assuming carbon emissions mirror wealth within countries, we were able to assign all the global emissions of any given year across the world's inhabitants. We found that of the world's 6 billion people in 2003, about 700 million were emitters of more than ten tons of CO_2 per year (we called them "high emitters") and accounted for about half of global emissions. Very roughly, among the high emitters there were 200 million Americans, 300 million citizens of OECD countries other than the United States, and 200 million residents of countries outside the OECD. By 2030, we estimated (based on several forecasts of future emissions across regions of the world) that there would be 1.2 billion high emitters, more than half of them outside the OECD, and that they would be associated with an

27. Shoibal Chakravarty, Ananth Chikkatur, Heleen de Coninck, Stephen Pacala, Robert Socolow & Massimo Tavoni, *Sharing Global CO_2 Emission Reductions Among One Billion High Emitters*, 106 PROCEEDINGS NAT'L ACAD. SCI. 11884 (2009).

even higher fraction of total emissions.[28] We conjectured that a focus on high emitters could help political leaders find common ground and conceivably could even bridge the divide between industrialized and developing countries that has thwarted "burden sharing" agreements for specific global emissions targets.[29]

Two degrees. Perhaps the most important self-deceptions today are associated with a fixation on the long-term goal called "two degrees" by much of the environmental community. "Two degrees" is shorthand for a precise objective: the goal is to limit the rise of the average surface temperature of the earth to two degrees Celsius, or 3.6 degrees Fahrenheit, relative to a time before the Industrial Revolution. Before 1800, for many centuries, that temperature is known to have been reasonably stable. Since 1800, it has climbed about 0.7 degrees Celsius. To oblige their environmental constituencies, many political leaders have endorsed the "two degrees" goal.

The goal is more than rhetorical; national leaders and environmentalists have linked it with three operational objectives that are more actionable. From the most distant in time to the most immediate, the three alternative restatements of the "two degrees" objective are: (1) a total atmospheric concentration of greenhouse gases at the end of the century that does not exceed the equivalent of 450 CO_2 molecules per million molecules of atmosphere; (2) a global total emissions rate of greenhouse gases at mid-century that does not exceed half of the current emissions rate; and (3) a trajectory for global emissions of greenhouse gases that peaks during the next decade. The "two degrees" goal and its three restatements are used interchangeably, which cuts through much ambiguity about exactly how such goals are connected. All formulations reveal a mindset that is common to the entire exercise: to create maximum pressure for action. The action most on the minds of the proponents of "two degrees" is deep transformation of lifestyles and the industrial

28. Shoibal Chakravarty, Robert Socolow & Massimo Tavoni, *A Focus on Individuals Can Guide Nations Towards a Low Carbon World*, CLIMATE SCI. & POL'Y (Nov. 13, 2009), http://www.climatescienceandpolicy.eu/2009/11/a-focus-on-individuals-can-guide-nations-towards-a-low-carbon-world/.

29. "Historical responsibility" for the CO_2 added to the atmosphere is the working name for another set of climate-related issues that are currently complicating international diplomacy. For some of the implications of historical responsibility, see Massimo Tavoni, Shoibal Chakravarty & Robert Socolow, *Safe vs. Fair: A Formidable Trade-Off in Tackling Climate Change*, 4 SUSTAINABILITY 210, 210–26 (2012).

structure of the OECD. Implications for developing country industrialization receive little attention.

The last point is where I return, once more, to the need to tell truths to ourselves. Pressure for action in the OECD is appropriate; being casual about the pathways to low-carbon industrialization is not. There is no way that any tough climate target can be reached without intense participation from the major developing countries that are building cities and infrastructure right now and locking in future emissions from their power plants and road systems and apartment blocks as they go. The environmental community must do all it can to make low-carbon industrialization salient to the decisionmakers—in both developing and industrialized countries. Now is the time to set in place the domestic and international institutions that can deliver low-carbon industrialization via involvement in the detailed features of the developing world's emerging infrastructure and cities.

Distorting the discussion of low-carbon industrialization is the reality of extreme poverty in the developing countries. One-third of the world's people, nearly all of them living in developing countries, are enjoying hardly any of the benefits of economic development. Moreover, according to the World Bank's projections of patterns of economic development, this fraction will stay at one-third for at least another two decades. Yet, as my colleagues and I showed quantitatively in the 2009 paper cited above, if all of the world's poorest people were to have the lifestyles of the nearly poor (with at least some vehicle transport, lighting, refrigeration, and electronics), there would be only a minimal increase in global CO_2 emissions.[30] Poverty eradication and the slowing of climate change are decoupled objectives, even though industrialization and climate change are not.

The "two degrees" target would be extremely ambitious even if a coordinated global effort were to materialize somehow. Yet, currently, the environmental community has little appetite for discussion of any goal that is less stringent. No one appears to be preparing for a time—possibly quite soon—when a consensus develops that a peaking of emissions in the 2020s will not occur and that therefore (at least in this meaning) "two degrees" will not be attained. The two-degree target has focused the mind and conveyed urgency. But it is already time for the environmental community to begin exploring targets that correspond to a relatively less difficult goal that nonetheless requires immediate, major national commitments and

30. Chakravarty et al., *supra* note 22.

international coordination.[31] An important reason to tell truths to ourselves is to protect ourselves against becoming disheartened when the world fails to stay below "two degrees" and thereby losing even more time developing the will to start again.

VI. PLANETARY IDENTITY

The Obama Administration has conducted an exercise to establish a price for CO_2 emissions, based on estimates of damages.[32] Already, such prices are entering regulations establishing efficiency and emissions standards at the Departments of Energy and Transportation and the Environmental Protection Agency. The question arises: Whose damages count? The Obama Administration decided that damage everywhere in the world had to be included. In effect, Americans will buy more efficient water heaters in part to reduce the severity of heat waves in France and droughts in Africa. By accounting for damage everywhere, the United States is promoting reciprocity: France might take damage to the United States into account when establishing its own emissions-related regulations. The overall result might be a larger total global investment in slowing climate change. Debate about which damages to include has already begun.[33]

The Obama Administration's choice will need to be defended. Someone must accept the assignment of communicating to political leaders and the general public that responding effectively to climate change will require some erosion of national sovereignty—an example of which is the inclusion of damages to citizens of other countries when a country decides how much to reduce its own CO_2 emissions. This task is fraught. Human beings are so deeply tribal. Nonetheless, I think the environmental community cannot evade this task, because climate change is a planetary phenomenon.

If my own experience is relevant, the transition toward a global sensibility may be self-enforcing for those who take climate change

31. For a mathematical discussion of alternative targets, see R.H. Socolow & S.H. Lam, *Good Enough Tools for Global Warming Policy Making*, 365 PHIL. TRANSACTIONS ROYAL SOC'Y A 897, 897–932 (2007).

32. Robert E. Kopp & Bryan K. Mignone, *The U.S. Government's Social Cost of Carbon Estimates After Their First Two Years: Pathways for Improvement*, ECON.: THE OPEN-ACCESS, OPEN-ASSESSMENT E-J., May 2012, at 4, *available at* http://www.economics-ejournal.org/economics/journalarticles/2012-15/version_1/count.

33. Jonathan S. Masur & Eric A. Posner, *Climate Regulation and the Limits of Cost-Benefit Analysis*, 99 CALIF. L. REV. 1557, 1591–96 (2011).

seriously. Although I had strong international interests beforehand, engaging with climate change has produced a planetary identity that augments my previous loyalties to family, town, religion, and nation. It will be interesting to see how a world of nation-states copes with ever greater numbers of people who have a planetary identity.

Working on climate change produces not only a new sensibility about geographical space but also a new sensibility about future time. In the past fifty years, thanks to science, we human beings have become far better informed about the history of our universe, our earth, and life. But we have become hardly at all more intelligent about *future* time. In particular, we have not devoted any systematic thought to our collective destiny as a species on this planet. Traditional religions dwell on what happens to us as *individuals* long-term, in heaven or hell, but not on what happens to humankind here on earth long-term. A new academic discipline may develop as scholars pursue the art and science of looking ahead. Perhaps it will be called Destiny Studies.

It seems quite within the capabilities of the human imagination to achieve a depth of understanding of the next fifty years of human civilization, and the next five hundred years, and the next five thousand years. At present, there is little capacity to distinguish between what we owe our grandchildren's generation and more distant future generations. In a continuing effort to define ethically responsible nuclear waste disposal, countries routinely allocate resources to preventing a cancer induced by a radioactive decay a million years from now. Roads and pipelines, parks and wilderness areas, historical buildings and institutional endowments—all of these raise issues with long time horizons. To deal adequately with the values at stake in decisions with long time horizons, of which climate change is just one example, humanity will need Destiny Studies.

In the course of this Essay, I have suggested many areas where the environmental community needs to ask itself difficult questions. In spite of how hard these questions are, when I take a fifty-year view I find grounds for optimism. The world has a terribly inefficient energy system today, so there is much room for improvement with focused effort. Most of the physical infrastructure that will operate in 2062 has not been built yet. And carbon emissions have just begun to be priced. Moreover, many smart and committed young people now find energy problems exciting and challenging, which was not the case even five years ago. Fortunately for all of us, our science has discovered threats fairly early, we can identify numerous helpful technologies, and we have a moral compass that tells us to care about all of those alive today and about the collective future of our species. What has seemed too hard becomes what simply must be done.