CHAPTER 10

THE ENVIRONMENT

But is progress sustainable? A common response to the good news about our health, wealth, and sustenance is that it cannot continue. As we infest the world with our teeming numbers, guzzle the earth's bounty heedless of its finitude, and foul our nests with pollution and waste, we are hastening an environmental day of reckoning. If overpopulation, resource depletion, and pollution don't finish us off, then climate change will.

As in the chapter on inequality, I won't pretend that all the trends are positive or that the problems facing us are minor. But I will present a way of thinking about these problems that differs from the lugubrious conventional wisdom and offers a constructive alternative to the radicalism or fatalism it encourages. The key idea is that environmental problems, like other problems, are solvable, given the right knowledge.

To be sure, the very idea that there *are* environmental problems cannot be taken for granted. From the vantage point of an individual, the Earth seems infinite, and our effects on it inconsequential. From the vantage points of science, the view is more troubling. The microscopic vantage point reveals pollutants that insidiously poison us and the species we admire and depend on; the macroscopic one reveals effects on ecosystems that may be imperceptible one action at a time but add up to tragic despoliation. Beginning in the 1960s, the environmental movement grew out of scientific knowledge (from ecology, public health, and earth and atmospheric sciences) and a Romantic reverence for nature. The movement made the health of the planet a permanent priority on humanity's agenda, and as we shall see, it deserves credit for substantial achievements—another form of human progress.

Ironically, many voices in the traditional environmental movement refuse to acknowledge that progress, or even that human progress is a worthy aspiration. In this chapter I will present a newer conception of environmentalism which shares the goal of protecting the air and water, species, and ecosystems but is grounded in Enlightenment optimism rather than Romantic declinism.

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Starting in the 1970s, the mainstream environmental movement latched onto a quasi-religious ideology, greenism, which can be found in the manifestoes of activists as diverse as Al Gore, the Unabomber, and Pope Francis.[1] Green ideology begins with an image of the Earth as a pristine ingénue which has been defiled by human rapacity. As Francis put it in his 2015 encyclical *Laudato Si'* (Praise be to you), "Our common home is like a sister with whom we share our life . . . [who] now cries out to us because of the harm we have inflicted on her." The harm, according to this narrative, has been inexorably worsening: "The earth, our home, is beginning to look more and more like an immense pile of filth." The root cause is the Enlightenment commitment to reason, science, and progress: "Scientific and technological progress cannot be equated with the progress of humanity and history," wrote Francis. "The way to a better future lies elsewhere," namely in an appreciation of "the mysterious network of relations between things" and (of course) "the treasure of Christian spiritual experience." Unless we repent our sins by degrowth, deindustrialization, and a rejection of the false gods of science, technology, and progress, humanity will face a ghastly reckoning in an environmental Judgment Day.

As with many apocalyptic movements, greenism is laced with misanthropy, including an indifference to starvation, an indulgence in ghoulish fantasies of a depopulated planet, and Nazi-like comparisons of human beings to vermin, pathogens, and cancer. For example, Paul Watson of the Sea Shepherd Conservation Society wrote, "We need to radically and intelligently reduce human populations to fewer than one billion. . . . Curing a body of cancer requires radical and invasive therapy, and therefore, curing the biosphere of the human virus will also require a radical and invasive approach."[2]

Recently an alternative approach to environmental protection has been championed by John Asafu-Adjaye, Jesse Ausubel, Andrew Balmford, Stewart Brand, Ruth DeFries, Nancy Knowlton, Ted Nordhaus, Michael Shellenberger, and others. It has been called Ecomodernism, Ecopragmatism, Earth Optimism, and the Blue-Green or Turquoise movement, though we can also think of it as Enlightenment Environmentalism or Humanistic Environmentalism.[3]

Ecomodernism begins with the realization that some degree of pollution is an inescapable consequence of the Second Law of Thermodynamics. When people use energy to create a zone of structure in their bodies and homes, they must increase entropy elsewhere in the environment in the form of waste, pollution, and other forms of disorder. The human species has always been ingenious at doing this—that's what differentiates us from other mammals—and it has never lived in harmony with the environment. When native peoples first set foot in an ecosystem, they typically hunted large animals to extinction, and often burned and cleared vast swaths of forest.[4] A dirty secret of the conservation movement is that wilderness preserves are set up only after indigenous peoples have been decimated or forcibly removed from them, including the national parks in the United States and the Serengeti in East Africa.[5] As the environmental historian William Cronon writes, "wilderness" is not a pristine sanctuary; it is itself a product of civilization.

When humans took up farming, they became more disruptive still. According to the paleoclimatologist William Ruddiman, the adoption of wet rice cultivation in Asia some five thousand years ago may have released so much methane into the atmosphere from rotting vegetation as to have changed the climate. "A good case can be made," he suggests, that "the people in the Iron Age and even the late Stone Age had a much greater per-capita impact on the earth's landscape than the average modern-day person."[6] And as Brand has pointed out (chapter 7), "natural farming" is a contradiction in terms. Whenever he hears the words *natural food,* he is tempted to rail:

> No product of agriculture is the slightest bit natural to an ecologist! You take a nice complex ecosystem, chop it into rectangles, clear it to the ground, and hammer it into perpetual early succession! You bust its sod, flatten it flat, and drench it with vast quantities of constant water! Then you populate it with uniform monocrops of profoundly damaged plants incapable of living on their own! Every food plant is a pathetic narrow specialist in one skill, inbred for thousands of years to a state of genetic idiocy! Those plants are so fragile, they had to domesticate humans just to take endless care of them![7]

A second realization of the ecomodernist movement is that industrialization has been good for humanity.[8] It has fed billions, doubled life spans, slashed extreme poverty, and, by replacing muscle with machinery, made it easier to end slavery, emancipate women, and educate children (chapters 7, 15, and 17). It has allowed people to read at night, live where they want, stay warm in winter, see the world, and multiply human contact. Any costs in pollution and habitat loss have to be weighed against these gifts. As the economist Robert Frank has put it, there is an optimal amount of pollution in the environment, just as there is an optimal amount of dirt in your house. Cleaner is better, but not at the expense of everything else in life.

The third premise is that the tradeoff that pits human well-being against environmental damage can be renegotiated by technology. How to enjoy more calories, lumens, BTUs, bits, and miles with less pollution and land is itself a technological problem, and one that the world is increasingly solving. Economists speak of the environmental Kuznets curve, a counterpart to the U-shaped arc for inequality as a function of economic growth. As countries first develop, they prioritize growth over environmental purity. But as they get richer, their thoughts turn to the environment.[9] If people can afford electricity only at the cost of some smog, they'll live with the smog, but when they can afford both electricity *and* clean air, they'll spring for the clean air. This can happen all the faster as technology makes cars and factories and power plants cleaner and thus makes clean air more affordable.

Economic growth bends the environmental Kuznets curve by advances not just in technology but in values. Some environmental concerns are entirely practical: people complain about smog in their city, or green space getting paved over. But other concerns are more spiritual. The fate of the black rhinoceros and the well-being of our descendants in the year 2525 are significant moral concerns, but worrying about them now is something of a luxury. As societies get richer and people no longer think about putting food on the table or a roof over their heads, their values climb a hierarchy of needs, and the scope of their concern expands in space and time. Ronald Inglehart and Christian Welzel, using data from the World Values Survey, have found that people with stronger emancipative values—tolerance, equality, freedom of thought and speech—which tend to go with affluence and education, are also more likely to recycle and to pressure governments and businesses into protecting the environment.[10]

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Ecopessimists commonly dismiss this entire way of thinking as the "faith that technology will save us." In fact it is a skepticism that the status quo will doom us—that knowledge will be frozen in its current state and people will robotically persist in their current behavior regardless of circumstances. Indeed, a naïve faith in stasis has repeatedly led to prophecies of environmental doomsdays that never happened.

The first is the "population bomb," which (as we saw in chapter 7) defused itself. When countries get richer and better educated, they pass through what demographers call the demographic transition.[11] First, death rates decline as nutrition and health improve. This does swell the population, but that is hardly something to bewail: as Johan Norberg notes, it happens not because people in poor countries start breeding like rabbits but because they stop dying like flies. In any case, the increase is temporary: birth rates peak and then decline, for at least two reasons. Parents no longer breed large broods as insurance against some of their children dying, and women, when they become better educated, marry later and delay having children. Figure 10-1 shows that the world population growth rate peaked at 2.1 percent a year in 1962, fell to 1.2 percent by 2010, and will probably fall to less than 0.5 percent by 2050 and be close to zero around 2070, when the population is projected to level off and then decline. Fertility rates have fallen most noticeably in developed regions like Europe and Japan, but they can

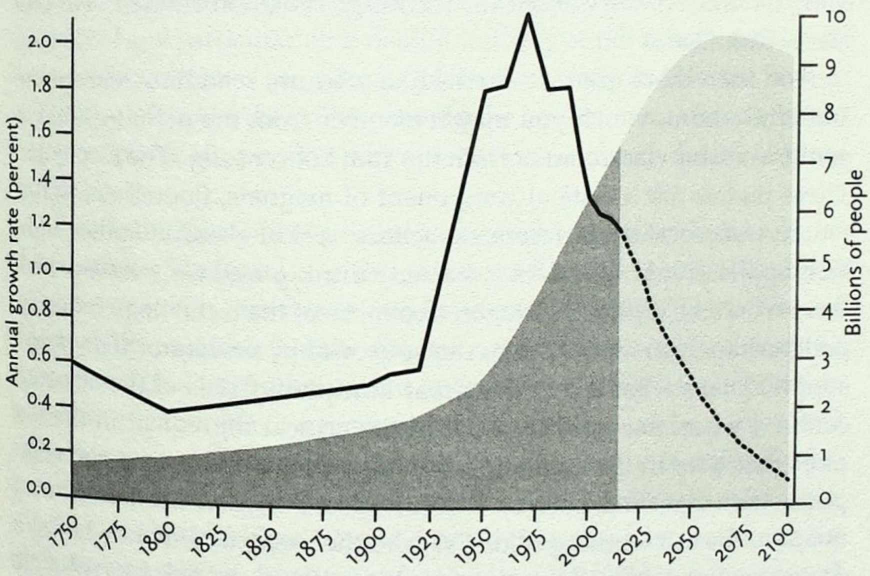

Figure 10-1: Population and population growth, 1750–2015 and projected to 2100

Sources: *Our World in Data*, Ortiz-Ospina & Roser 2016d. **1750–2015:** United Nations Population Division and *History Database of the Global Environment* (HYDE), PBL Netherlands Environmental Assessment Agency (undated). **Post-2015 projections:** International Institute for Applied Systems Analysis, Medium Projection (aggregate of country-specific estimates, taking education into account), Lutz, Butz, & Samir 2014.

suddenly collapse, often to demographers' surprise, in other parts of the world. Despite the widespread belief that Muslim societies are resistant to the social changes that have transformed the West and will be indefinitely rocked by youthquakes, Muslim countries have seen a 40 percent decline in fertility over the past three decades, including a 70 percent drop in Iran and 60 percent drops in Bangladesh and in seven Arab countries.[12]

The other scare from the 1960s was that the world would run out of resources. But resources just refuse to run out. The 1980s came and went without the famines that were supposed to starve tens of millions of Americans and billions of people worldwide. Then the year 1992 passed and, contrary to projections from the 1972 bestseller *The Limits to Growth* and similar philippics, the world did not exhaust its aluminum, copper, chromium, gold, nickel, tin, tungsten, or zinc. (In 1980 Paul Ehrlich famously bet the economist Julian Simon that five of these metals would become scarcer and hence more expensive by the end of the decade; he lost all five bets. Indeed, most metals and minerals are cheaper today than they were in 1960.)[13] From the 1970s to the early 2000s newsmagazines periodically illustrated cover stories on the world's oil supply with a gas gauge pointing to Empty. In 2013 *The Atlantic* ran a cover story about the fracking revolution entitled "We Will Never Run Out of Oil."

And then there are rare earths like yttrium, scandium, europium, and lanthanum, which you may remember from the periodic table in your chemistry classroom or from the Tom Lehrer song "The Elements." These metals are a critical component of magnets, fluorescent lights, video screens, catalysts, lasers, capacitors, optical glass, and other high-tech applications. When they started running out, we were warned, there would be critical shortages, a collapse of the technology industry, and perhaps war with China, the source of 95 percent of the world's supply. That's what led to the Great Europium Crisis of the late 20th century, when the world ran out of the critical ingredient in the red phosphor dots in the cathode-ray tubes in color televisions and computer monitors and society was divided between the haves, who hoarded the last working color TVs, and the angry have-nots, who were forced to make do with black-and-white. What, you never heard of it? Among the reasons there was no such crisis was that cathode-ray tubes were superseded by liquid crystal displays made of common elements.[14] And the Rare Earths War? In reality, when China squeezed its exports in 2010 (not because of shortages but as a geopolitical and mercantilist weapon), other countries started extracting rare earths from their own mines, recycling them from industrial waste, and re-engineering products so they no longer needed them.[15]

When predictions of apocalyptic resource shortages repeatedly fail to come true, one has to conclude either that humanity has miraculously escaped from certain death again and again like a Hollywood action hero or that there is a flaw in the thinking that predicts apocalyptic resource shortages. The flaw has been pointed out many times.[16] Humanity does not suck resources from the earth like a straw in a milkshake until a gurgle tells it that the container is empty. Instead, as the most easily extracted supply of a resource becomes scarcer, its price rises, encouraging people to conserve it, get at the less accessible deposits, or find cheaper and more plentiful substitutes.

Indeed, it's a fallacy to think that people "need resources" in the first place.[17] They need ways of growing food, moving around, lighting their homes, displaying information, and other sources of well-being. They satisfy these needs with *ideas:* with recipes, formulas, techniques, blueprints, and algorithms for manipulating the physical world to give them what they want. The human mind, with its recursive combinatorial power, can explore an infinite space of ideas, and is not limited by the quantity of any particular kind of stuff in the ground. When one idea no longer works, another can take its place. This doesn't defy the laws of probability but obeys them. Why should the laws of nature have allowed *exactly one* physically possible way of satisfying a human desire, no more and no less?[18]

Admittedly, this way of thinking does not sit well with the ethic of "sustainability." In figure 10-2, the cartoonist Randall Munroe illustrates what's wrong with this vogue word and sacred value. The doctrine of sustainability assumes that the current rate of use of a resource may be extrapolated into the future until it rams into a ceiling. The implication is that we must switch to a renewable resource that can be replenished at the rate we use it, indefinitely. In reality, societies have always abandoned a resource for a better one long before the old one was exhausted. It's often said that the Stone Age did not end because the world ran out of stones, and that has been true of energy as well. "Plenty of wood and hay remained to be exploited when the world shifted to coal," Ausubel notes. "Coal abounded when oil rose. Oil abounds now as methane [natural gas] rises."[19] As we will see, gas in turn may be replaced by energy sources still lower in carbon well before the last cubic foot goes up in a blue flame.

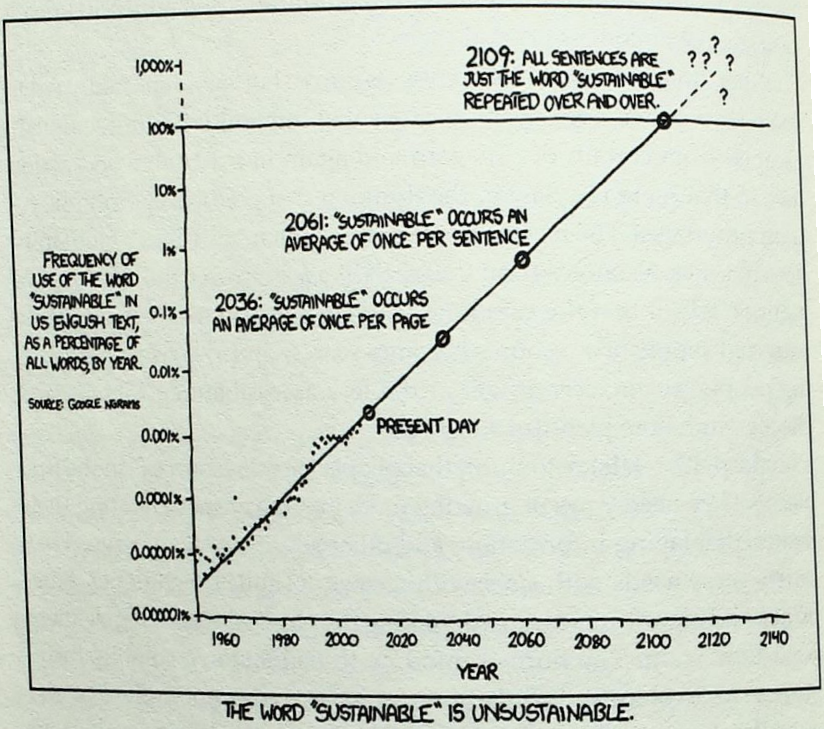

Figure 10-2: Sustainability, 1955–2109

Source: Randall Munroe, XKCD, http://xkcd.com/1007/. Credit: Randall Munroe, xkcd.com.

The supply of food, too, has grown exponentially (as we saw in chapter 7), even though no single method of growing it has ever been sustainable. In *The Big Ratchet: How Humanity Thrives in the Face of Natural Crisis*, the geographer Ruth DeFries describes the sequence as "ratchet-hatchet-pivot." People discover a way of growing more food, and the population ratchets upward. The method fails to keep up with the demand or develops unpleasant side effects, and the hatchet falls. People then pivot to a new method. At various times, farmers have pivoted to slash-and-burn horticulture, night soil (a euphemism for human feces), crop rotation, guano, saltpeter, ground-up bison bones, chemical fertilizer, hybrid crops, pesticides, and the Green Revolution.[20] Future pivots may include genetically modified organisms, hydroponics, aeroponics, urban vertical farms, robotic harvesting, meat cultured in vitro, artificial intelligence algorithms fed by GPS and biosensors, the recovery of energy and fertilizer from sewage, aquaculture with fish that eat tofu instead of other fish, and who knows what else—as long as people are allowed to indulge their ingenuity.[21] Though water is one resource that people will never pivot away from, farmers could save massive amounts if they switched to Israeli-style precision farming. And if the world develops abundant carbon-free energy sources (a topic we will explore later), it could get what it needs by desalinating seawater.[22]

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Not only have the disasters prophesied by 1970s greenism failed to take place, but improvements that it deemed impossible *have* taken place. As the world has gotten richer and crested the environmental curve, nature has begun to rebound.[23] Pope Francis's "immense pile of filth" is the vision of someone who has woken up thinking it's 1965, the era of belching smokestacks, waterfalls of sewage, rivers catching fire, and jokes about New Yorkers not liking to breathe air they can't see. Figure 10-3 shows that since 1970, when the Environmental Protection Agency was established, the United States has slashed its emissions of five air pollutants by almost two-thirds. Over the same period, the population grew by more than 40 percent, and those people drove twice as many miles and became two and a half times richer. Energy use has leveled off, and even

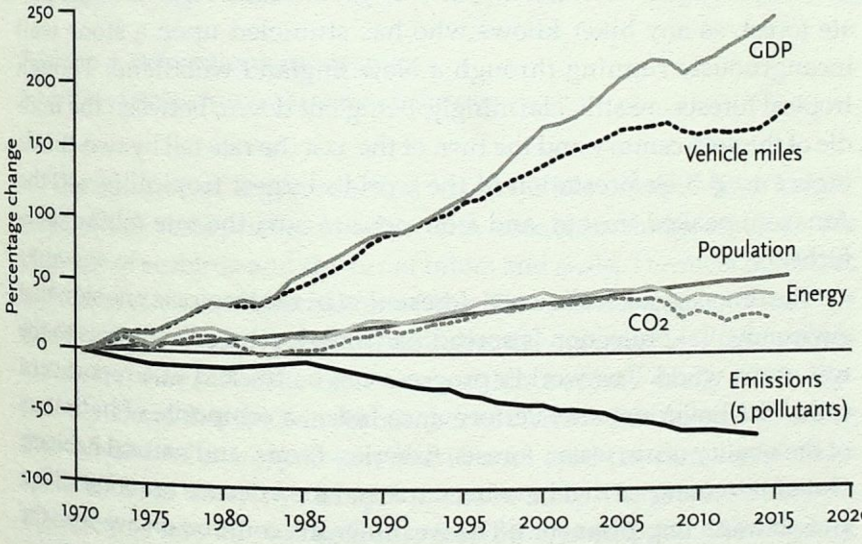

Figure 10-3: Pollution, energy, and growth, US, 1970–2015

Sources: US Environmental Protection Agency 2016, based on the following sources. **GDP**: Bureau of Economic Analysis. **Vehicle miles traveled:** Federal Highway Administration. **Population:** US Census Bureau. **Energy Consumption:** US Department of Energy. **CO_2:** US Greenhouse Gas Inventory Report. **Emissions** (carbon monoxide, oxides of nitrogen, particulate matter smaller than 10 micrometers, sulfur dioxide, and volatile organic compounds): EPA, https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data.

carbon dioxide emissions have turned a corner, a point to which we will return. The declines don't just reflect an offshoring of heavy industry to the developing world, because the bulk of energy use and emissions comes from transportation, heating, and electricity generation, which cannot be outsourced. Rather, they mainly reflect gains in efficiency and emission control. These diverging curves refute both the orthodox Green claim that only degrowth can curb pollution and the orthodox right-wing claim that environmental protection must sabotage economic growth and people's standard of living.

Many of the improvements can be seen with the naked eye. Cities are less often shrouded in purple-brown haze, and London no longer has the fog—actually coal smoke—that was immortalized in Impressionist paintings, gothic novels, the Gershwin song, and the brand of raincoats. Urban waterways that had been left for dead—including Puget Sound, Chesapeake Bay, Boston Harbor, Lake Erie, and the Hudson, Potomac, Chicago, Charles, Seine, Rhine, and Thames rivers (the last described by Disraeli as "a Stygian pool reeking with ineffable and intolerable horrors")—have been recolonized by fish, birds, marine mammals, and sometimes swimmers. Suburbanites are seeing wolves, foxes, bears, bobcats, badgers, deer, ospreys, wild turkeys, and bald eagles. As agriculture becomes more efficient (chapter 7), farmland returns to temperate forest, as any hiker knows who has stumbled upon a stone wall incongruously running through a New England woodland. Though tropical forests are still, alarmingly, being cut down, between the middle of the 20th century and the turn of the 21st the rate fell by two-thirds (figure 10-4).[24] Deforestation of the world's largest tropical forest, the Amazon, peaked in 1995, and from 2004 to 2013 the rate fell by four-fifths.[25]

The time-lagged decline of deforestation in the tropics is one sign that environmental protection is spreading from developed countries to the rest of the world. The world's progress can be tracked in a report card called the Environmental Performance Index, a composite of indicators of the quality of air, water, forests, fisheries, farms, and natural habitats. Out of 180 countries that have been tracked for a decade or more, all but two show an improvement.[26] The wealthier the country, on average, the cleaner its environment: the Nordic countries were cleanest; Afghanistan, Bangladesh, and several sub-Saharan African countries, the most compromised. Two of the deadliest forms of pollution—contaminated drinking water and indoor cooking smoke—are afflictions of poor countries.[27] But as poor countries have gotten richer in recent decades, they are escaping these blights: the proportion of the world's population that drinks tainted water has fallen by five-eighths, the proportion breathing cooking smoke by a third.[28] As Indira Gandhi said, "Poverty is the greatest polluter."[29]

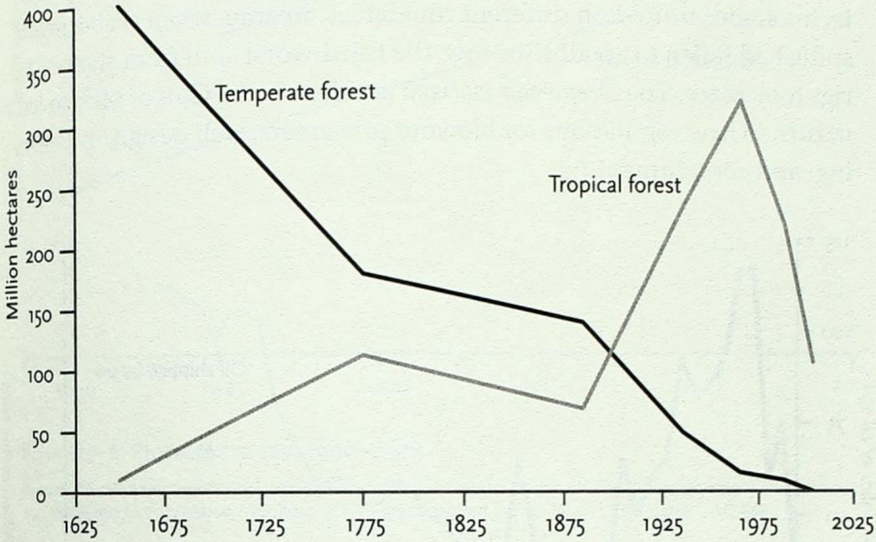

Figure 10-4: Deforestation, 1700–2010

Source: United Nations Food and Agriculture Organization 2012, p. 9.

The epitome of environmental insults is the oil spill from tanker ships, which coats pristine beaches with toxic black sludge and fouls the plumage of seabirds and the fur of otters and seals. The most notorious accidents, such as the breakup of the *Torrey Canyon* in 1967 and the *Exxon Valdez* in 1989, linger in our collective memory, and few people are aware that seaborne oil transport has become vastly safer. Figure 10-5 shows that the annual number of oil spills has fallen from more than a hundred in 1973 to just five in 2016 (and the number of *major* spills fell from thirty-two in 1978 to one in 2016). The graph also shows that even as less oil was spilled, more oil was shipped; the crossing curves provide additional evidence that environmental protection is compatible with economic growth. It's no mystery that oil companies should *want* to reduce tanker accidents, because their interests and those of the environment coincide: oil spills are a public-relations disaster (especially when the name of the company is emblazoned on a cracked-up ship), bring on huge fines, and of course waste valuable oil. More interesting is the fact that the companies have largely succeeded. Technologies follow a learning curve and become less hazardous over time as the boffins design out the most dangerous vulnerabilities (a point we'll return to in chapter 12). But people remember the accidents and are unaware of the incremental improvements. The improvements in different technologies unfold on different timetables: in 2010, when seaborne oil spills had fallen to an all-time low, the third-worst spill from stationary rigs took place. The *Deepwater Horizon* accident in the Gulf of Mexico led in turn to new regulations for blowout preventers, well design, monitoring, and containment.[30]

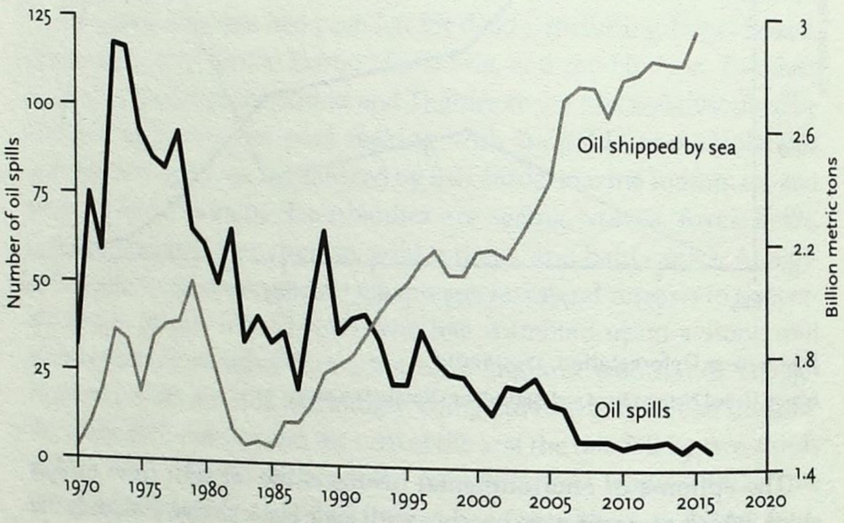

Figure 10-5: Oil spills, 1970–2016

Source: *Our World in Data*, Roser 2016r, based on data (updated) from the International Tanker Owners Pollution Federation, http://www.itopf.com/knowledge-resources/data-statistics/statistics/. Oil spills include all those that result in the loss of at least 7 metric tons of oil. Oil shipped consists of "total crude oil, petroleum product, and gas loaded."

In another advance, entire swaths of land and ocean have been protected from human use altogether. Conservation experts are unanimous in their assessment that the protected areas are still inadequate, but the momentum is impressive. Figure 10-6 shows that the proportion of the Earth's land set aside as national parks, wildlife reserves, and other protected areas has grown from 8.2 percent in 1990 to 14.8 percent in 2014—an area double the size of the United States. Marine conservation areas have grown as well, more than doubling during this period and now protecting more than 12 percent of the world's oceans.

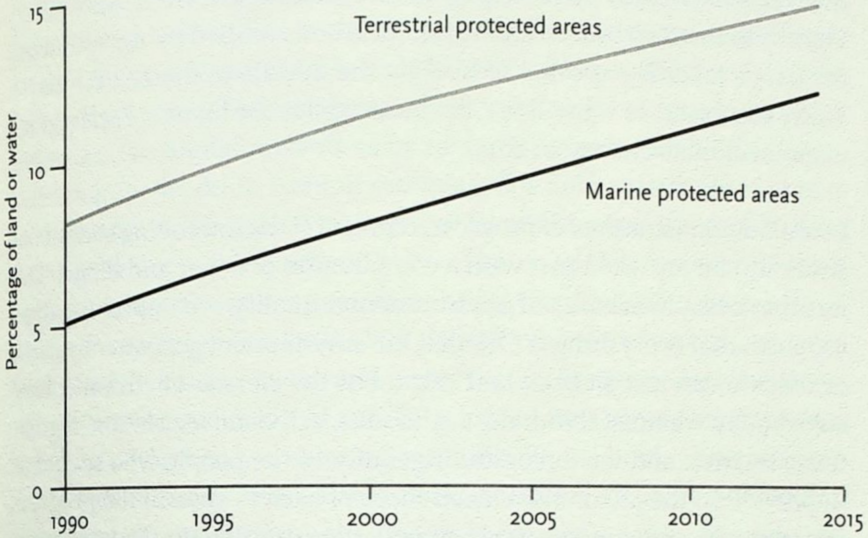

Figure 10-6: Protected areas, 1990–2014

Source: World Bank 2016h and 2017, based on data from the United Nations Environment Programme and the World Conservation Monitoring Centre, compiled by the World Resources Institute.

Thanks to habitat protection and targeted conservation efforts, many beloved species have been pulled from the brink of extinction, including albatrosses, condors, manatees, oryxes, pandas, rhinoceroses, Tasmanian devils, and tigers; according to the ecologist Stuart Pimm, the overall rate of extinctions has been reduced by 75 percent.[31] Though many species remain in precarious straits, a number of ecologists and paleontologists believe that the claim that humans are causing a mass extinction like the Permian and Cretaceous is hyperbolic. As Brand notes, "No end of specific wildlife problems remain to be solved, but describing them too often as extinction crises has led to a general panic that nature is extremely fragile or already hopelessly broken. That is not remotely the case. Nature as a whole is exactly as robust as it ever was—maybe more so. . . . Working with that robustness is how conservation's goals get reached."[32]

Other improvements are global in scope. The 1963 treaty banning atmospheric nuclear testing eliminated the most terrifying form of pollution of all, radioactive fallout, and proved that the world's nations could agree on measures to protect the planet even in the absence of a world government. Global cooperation has dealt with several other challenges since. International treaties on the reduction of sulfur emissions and other forms of "long-range transboundary air pollution" signed in the 1980s and 1990s have helped to eliminate the scare of acid rain.[33] Thanks to the 1987 ban on chlorofluorocarbons ratified by 197 countries, the ozone layer is expected to heal by the middle of the 21st century.[34] These successes, as we will see, set the stage for the historic Paris Agreement on climate change in 2015.

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Like all demonstrations of progress, reports on the improving state of the environment are often met with a combination of anger and illogic. The fact that many measures of environmental quality are improving does *not* mean that everything is OK, that the environment got better by itself, or that we can just sit back and relax. For the cleaner environment we enjoy today we must thank the arguments, activism, legislation, regulations, treaties, and technological ingenuity of the people who sought to improve it in the past.[35] We'll need more of each to sustain the progress we've made, prevent reversals (particularly under the Trump presidency), and extend it to the wicked problems that still face us, such as the health of the oceans and, as we shall see, atmospheric greenhouse gases.

But for many reasons, it's time to retire the morality play in which modern humans are a vile race of despoilers and plunderers who will hasten the apocalypse unless they undo the Industrial Revolution, renounce technology, and return to an ascetic harmony with nature. Instead, we can treat environmental protection as a problem to be solved: how can people live safe, comfortable, and stimulating lives with the least possible pollution and loss of natural habitats? Far from licensing complacency, our progress so far at solving this problem emboldens us to strive for more. It also points to the forces that pushed this progress along.

One key is to decouple productivity from resources: to get more human benefit from less matter and energy. This puts a premium on *density*.[36] As agriculture becomes more intensive by growing crops that are bred or engineered to produce more protein, calories, and fiber with less land, water, and fertilizer, farmland is spared, and it can morph back to natural habitats. (Ecomodernists point out that organic farming, which needs far more land to produce a kilogram of food, is neither green nor sustainable.) As people move to cities, they not only free up land in the countryside but need fewer resources for commuting, building, and heating, because one man's ceiling is another man's floor. As trees are harvested from dense plantations, which have five to ten times the yield of natural forests, forest land is spared, together with its feathered, furry, and scaly inhabitants.

All these processes are helped along by another friend of the Earth, *dematerialization*. Progress in technology allows us to do more with less. An aluminum soda can used to weigh three ounces; today it weighs less than half an ounce. Mobile phones don't need miles of telephone poles and wires. The digital revolution, by replacing atoms with bits, is dematerializing the world in front of our eyes. The cubic yards of vinyl that used to be my music collection gave way to cubic inches of compact discs and then to the nothingness of MP3s. The river of newsprint flowing through my apartment has been stanched by an iPad. With a terabyte of storage on my laptop I no longer buy paper by the ten-ream box. And just think of all the plastic, metal, and paper that no longer go into the forty-odd consumer products that can be replaced by a single smartphone, including a telephone, answering machine, phone book, camera, camcorder, tape recorder, radio, alarm clock, calculator, dictionary, Rolodex, calendar, street maps, flashlight, fax, and compass—even a metronome, outdoor thermometer, and spirit level.

Digital technology is also dematerializing the world by enabling the sharing economy, so that cars, tools, and bedrooms needn't be made in huge numbers that sit around unused most of the time. The advertising analyst Rory Sutherland has noted that dematerialization is also being helped along by changes in the criteria of social status.[37] The most expensive London real estate today would have seemed impossibly cramped to wealthy Victorians, but the city center is now more fashionable than the suburbs. Social media have encouraged younger people to show off their experiences rather than their cars and wardrobes, and hipsterization leads them to distinguish themselves by their tastes in beer, coffee, and music. The era of the Beach Boys and *American Graffiti* is over: half of American eighteen-year-olds do not have a driver's license.[38]

The expression "Peak Oil," which became popular after the energy crises of the 1970s, refers to the year that the world would reach its maximum extraction of petroleum. Ausubel notes that because of the demographic transition, densification, and dematerialization, we may have reached Peak Children, Peak Farmland, Peak Timber, Peak Paper, and Peak Car. Indeed, we may be reaching Peak Stuff: of a hundred commodities Ausubel plotted, thirty-six have peaked in absolute use in the United States, and another fifty-three may be poised to drop (including water, nitrogen, and electricity), leaving only eleven that are still growing. Britons, too, have reached Peak Stuff, having reduced their annual use of material from 15.1 metric tons per person in 2001 to 10.3 metric tons in 2013.[39]

These remarkable trends required no coercion, legislation, or moralization; they spontaneously unfolded as people made choices about how to live their lives. The trends certainly don't show that environmental legislation is dispensable—by all accounts, environmental protection agencies, mandated energy standards, endangered species protection, and national and international clean air and water acts have had enormously beneficial effects.[40] But they suggest that the tide of modernity does not sweep humanity headlong toward ever more unsustainable use of resources. Something in the nature of technology, particularly information technology, works to decouple human flourishing from the exploitation of physical stuff.

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Just as we must not accept the narrative that humanity inexorably despoils every part of the environment, we must not accept the narrative that every part of the environment will rebound under our current practices. An enlightened environmentalism must face the facts, hopeful or alarming, and one set of facts is unquestionably alarming: the effect of greenhouse gases on the earth's climate.[41]

Whenever we burn wood, coal, oil, or gas, the carbon in the fuel is oxidized to form carbon dioxide (CO_2), which wafts into the atmosphere. Though some of the CO_2 dissolves in the ocean, chemically combines with rocks, or is taken up by photosynthesizing plants, these natural sinks cannot keep up with the 38 billion tons we dump into the atmosphere each year. As gigatons of carbon laid down during the Carboniferous Period have gone up in smoke, the concentration of CO_2 in the atmosphere has risen from about 270 parts per million before the Industrial Revolution to more than 400 parts today. Since CO_2, like the glass in a greenhouse, traps heat radiating from the Earth's surface, the global average temperature has risen as well, by about .8° Celsius (1.4° Fahrenheit), and 2016 was the hottest year on record, with 2015 coming in second and 2014 coming in third. The atmosphere has also been warmed by the clearing of carbon-eating forests and by the release of methane (an even more potent greenhouse gas) from leaky gas wells, melting permafrost, and the orifices at both ends of cattle. It could become warmer still in a runaway feedback loop if white, heat-reflecting snow and ice are replaced by dark, heat-absorbing land and water, if the melting of permafrost accelerates, and if more water vapor (yet another greenhouse gas) is sent into the air.

If the emission of greenhouse gases continues, the Earth's average temperature will rise to at least 1.5°C (2.7°F) above the preindustrial level by the end of the 21st century, and perhaps to 4°C (7.2°F) above that level or more. That will cause more frequent and more severe heat waves, more floods in wet regions, more droughts in dry regions, heavier storms, more severe hurricanes, lower crop yields in warm regions, the extinction of more species, the loss of coral reefs (because the oceans will be both warmer and more acidic), and an average rise in sea level of between 0.7 and 1.2 meters (2 and 4 feet) from both the melting of land ice and the expansion of seawater. (Sea level has already risen almost eight inches since 1870, and the rate of the rise appears to be accelerating.) Low-lying areas would be flooded, island nations would disappear beneath the waves, large stretches of farmland would no longer be arable, and millions of people would be displaced. The effects could get still worse in the 22nd century and beyond, and in theory could trigger upheavals such as a diversion of the Gulf Stream (which would turn Europe into Siberia) or a collapse of Antarctic ice sheets. A rise of 2°C is considered the most that the world could reasonably adapt to, and a rise of 4°C, in the words of a 2012 World Bank report, "simply must not be allowed to occur."[42]

To keep the rise to 2°C or less, the world would, at a minimum, have to reduce its greenhouse gas emissions by half or more by the middle of the 21st century and eliminate them altogether before the turn of the 22nd.[43] The challenge is daunting. Fossil fuels provide 86 percent of the world's energy, powering almost every car, truck, train, plane, ship, tractor, furnace, and factory on the planet, together with most of its electricity plants.[44] Humanity has never faced a problem like it.

One response to the prospect of climate change is to deny that it is occurring or that human activity is the cause. It's completely appropriate, of course, to challenge the hypothesis of anthropogenic climate change on scientific grounds, particularly given the extreme measures it calls for if it is true. The great virtue of science is that a true hypothesis will, in the long run, withstand attempts to falsify it. Anthropogenic climate change is the most vigorously challenged scientific hypothesis in history. By now, all the major challenges—such as that global temperatures have stopped rising, that they only seem to be rising because they were measured in urban heat islands, or that they really are rising but only because the sun is getting hotter—have been refuted, and even many skeptics have been convinced.[45] A recent survey found that exactly *four* out of 69,406 authors of peer-reviewed articles in the scientific literature rejected the hypothesis of anthropogenic global warming, and that "the peer-reviewed literature contains no convincing evidence against [the hypothesis]."[46]

Nonetheless, a movement within the American political right, heavily underwritten by fossil fuel interests, has prosecuted a fanatical and mendacious campaign to deny that greenhouse gases are warming the planet.[47] In doing so they have advanced the conspiracy theory that the scientific community is fatally infected with political correctness and ideologically committed to a government takeover of the economy. As someone who considers himself something of a watchdog for politically correct dogma in academia, I can state that this is nonsense: physical scientists have no such agenda, and the evidence speaks for itself.[48] (And it's precisely because of challenges like this that scholars in all fields have a duty to secure the credibility of the academy by *not* enforcing political orthodoxies.)

To be sure, there are judicious climate change skeptics, sometimes called lukewarmers, who accept the mainstream science but accentuate the positive.[49] They favor the fringe of the envelope of possibilities with the slowest temperature rise, note that the worst-case scenarios with runaway feedback are hypothetical, point out that moderately higher temperatures and CO_2 have benefits in crop yields that should be traded off against their costs, and argue that if countries are allowed to get as rich as possible (without growth-sapping restrictions on fossil fuels) they will be better equipped to adapt to the climate change that does occur. But as the economist William Nordhaus points out, this is a rash gamble in what he calls the Climate Casino.[50] If the status quo presents, say, an even chance that the world will get significantly worse, and a 5 percent chance that it will pass a tipping point and face a catastrophe, it would be prudent to take preventive action even if the catastrophic outcome is not certain, just as we buy fire extinguishers and insurance for our houses and don't keep open cans of gasoline in our garages. Since dealing with climate change will be a multidecade effort, there's plenty of time to back off if temperature, sea level, and ocean acidity happily stop rising.

Another response to climate change, from the far left, seems designed to vindicate the conspiracy theories of the far right. According to the "climate justice" movement popularized by the journalist Naomi Klein in her 2014 bestseller *This Changes Everything: Capitalism vs. the Climate*, we should not treat the threat of climate change as a challenge to prevent climate change. No, we should treat it as an opportunity to abolish free markets, restructure the global economy, and remake our political system.[51] In one of the more surreal episodes in the history of environmental politics, Klein joined the infamous David and Charles Koch, the billionaire oil industrialists and bankrollers of climate change denial, in helping to defeat a 2016 Washington state ballot initiative that would have implemented the country's first carbon tax, the policy measure which almost every analyst endorses as a prerequisite to dealing with climate change.[52] Why? Because the measure was "right-wing friendly," and it did not "make the polluters pay, and put their immoral profits to work repairing the damage they have knowingly created." In a 2015 interview Klein even opposed analyzing climate change quantitatively:

> We're not going to win this as bean counters. We can't beat the bean counters at their own game. We're going to win this because this is an issue of values, human rights, right and wrong. We just have this brief period where we also have to have some nice stats that we can wield, but we shouldn't lose sight of the fact that what actually moves people's hearts are the arguments based on the value of life.[53]

Blowing off quantitative analysis as "bean-counting" is not just anti-intellectual but works *against* "values, human rights, right and wrong." Someone who values human life will favor the policies that have the greatest chance of saving people from being displaced or starved while furnishing them with the means to live healthy and fulfilled lives.[54] In a universe governed by the laws of nature rather than magic and deviltry, that requires "bean-counting." Even when it comes to the purely rhetorical challenge of "moving people's hearts," efficacy matters: people are likelier to accept the fact of global warming when they are told that the problem is solvable by innovations in policy and technology than when they are given dire warnings about how awful it will be.[55]

Another common sentiment about how to prevent climate change is expressed in this letter, of a kind I receive every now and again:

> Dear Professor Pinker
>
> We need to do something about global warming. Why don't the Nobel prize winning scientists sign a petition? Why don't they tell the blunt truth, that the politicians are pigs who don't care how many people get killed in floods and droughts?
>
> Why don't you and some friends start a movement on the Internet to get people to sign a pledge that they will make real sacrifices to fight global warming. Because that's the problem. Nobody wants to make any sacrifices. People should pledge to never fly in airplanes except in

> dire emergencies, because airplanes burn so much fuel. People should pledge to eat no meat on at least three days per week, because meat production adds so much carbon to the atmosphere. People should pledge to buy no jewelry, ever, because refining gold and silver is so energy-intensive. We should abolish artistic pottery, because it burns so much carbon. The potters in university art departments are just going to have to accept the fact that we can't go on like this.

Forgive the bean-counting, but even if everyone gave up their jewelry, it would not make a scratch in the world's emission of greenhouse gases, which are dominated by heavy industry (29 percent), buildings (18 percent), transport (15 percent), land-use change (15 percent), and the energy needed to supply energy (13 percent). (Livestock is responsible for 5.5 percent, mostly methane rather than CO_2, and aviation for 1.5 percent.)[56] Of course my correspondent suggested forgoing jewelry and pottery not because of the *effect* but because of the *sacrifice*, and it's no surprise that she singled out jewelry, the quintessential luxury. I bring up her ingenuous suggestion to illustrate two psychological impediments we face in dealing with climate change.

The first is cognitive. People have trouble thinking in scale: they don't differentiate among actions that would reduce CO_2 emissions by thousands of tons, millions of tons, and billions of tons.[57] Nor do they distinguish among level, rate, acceleration, and higher-order derivatives—between actions that would affect the rate of *increase* in CO_2 emissions, affect the *rate* of CO_2 emissions, affect the *level* of CO_2 in the atmosphere, and affect global *temperatures* (which will rise even if the level of CO_2 remains constant). Only the last of these matters, but if one doesn't think in scale and in orders of change, one can be satisfied with policies that accomplish nothing.

The other impediment is moralistic. As I mentioned in chapter 2, the human moral sense is not particularly moral; it encourages dehumanization ("politicians are pigs") and punitive aggression ("make the polluters pay"). Also, by conflating profligacy with evil and asceticism with virtue, the moral sense can sanctify pointless displays of sacrifice.[58] In many cultures people flaunt their righteousness with vows of fasting, chastity, self-abnegation, bonfires of the vanities, and animal (or sometimes human) sacrifice. Even in modern societies—according to studies I've done with the psychologists Jason Nemirow, Max Krasnow, and Rhea Howard—people esteem others according to how much time or money they forfeit in their altruistic acts rather than by how much good they accomplish.[59]

Much of the public chatter about mitigating climate change involves voluntary sacrifices like recycling, reducing food miles, unplugging chargers, and so on. (I myself have posed for posters in several of these campaigns led by Harvard students.)[60] But however virtuous these displays may feel, they are a distraction from the gargantuan challenge facing us. The problem is that carbon emissions are a classic public goods game, also known as a Tragedy of the Commons. People benefit from everyone else's sacrifices and suffer from their own, so everyone has an incentive to be a free rider and let everyone else make the sacrifice, and everyone suffers. A standard remedy for public goods dilemmas is a coercive authority that can punish free riders. But any government with the totalitarian power to abolish artistic pottery is unlikely to restrict that power to maximizing the common good. One can, alternatively, daydream that moral suasion is potent enough to induce everyone to make the necessary sacrifices. But while humans do have public sentiments, it's unwise to let the fate of the planet hinge on the hope that billions of people will simultaneously volunteer to act against their interests. Most important, the sacrifice needed to bring carbon emissions down by half and then to zero is far greater than forgoing jewelry: it would require forgoing electricity, heating, cement, steel, paper, travel, and affordable food and clothing.

Climate justice warriors, indulging the fantasy that the developing world will do just that, advocate a regime of "sustainable development." As Shellenberger and Ted Nordhaus satirize it, that consists of "small co-ops in the Amazon forest where peasant farmers and Indians would pick nuts and berries to sell to Ben and Jerry's for their 'Rainforest Crunch' flavor."[61] They would be allowed solar panels that could light an LED or charge a cell phone, but nothing more. Needless to say, the people who actually live in those countries have a different idea. Escaping from poverty requires abundant energy. The proprietor of *HumanProgress,* Marian Tupy, points out that in 1962 Botswana and Burundi were equally destitute, with an annual per capita income of $70, and neither emitted much CO_2. By 2010, Botswanans earned $7,650 a year, 32 times as much as the still-poor Burundians, and they emitted 89 times as much CO_2.[62]

Faced with such facts, climate justice warriors reply that rather than enriching poor nations, we should impoverish rich ones, switching back, for example, to "labor-intensive agriculture" (to which an appropriate reply is: You first). Shellenberger and Nordhaus note how far progressive politics has moved from the days in which rural electrification and economic development were among its signature projects: "In the name of democracy it now offers the global poor not what they want—cheap electricity—but more of what they don't want, namely intermittent and expensive power."[63]

Economic progress is an imperative in rich and poor countries alike precisely because it will be needed to adapt to the climate change that does occur. Thanks in good part to prosperity, humanity has been getting healthier (chapters 5 and 6), better fed (chapter 7), more peaceful (chapter 11), and better protected from natural hazards and disasters (chapter 12). These advances have made humanity more resilient to natural and human-made threats: disease outbreaks don't become pandemics, crop failures in one region are alleviated by surpluses in another, local skirmishes are defused before they erupt into war, populations are better protected against storms, floods, and droughts. Part of our response to climate change must be to ensure that these gains in resilience continue to outpace the threats that a warming planet will throw at it. Every year that developing countries get richer, they will have more resources for building seawalls and reservoirs, improving public health services, and moving people away from rising seas. For that reason they must not be kept in energy poverty—but neither does it make sense for them to raise incomes with massive coal burning that will overwhelm everyone later with weather disasters.[64]

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How, then, *should* we deal with climate change? Deal with it we must. I agree with Pope Francis and the climate justice warriors that preventing climate change is a moral issue because it has the potential to harm billions, particularly the world's poor. But morality is different from moralizing, and is often poorly served by it. (The Pope's encyclical backfired, *decreasing* concern about climate change among the conservative Catholics who were aware of it.)[65] It may be satisfying to demonize the fossil fuel corporations that sell us the energy we want, or to signal our virtue by making conspicuous sacrifices, but these indulgences won't prevent destructive climate change.

The enlightened response to climate change is to figure out how to get the most energy with the least emission of greenhouse gases. There is, to be sure, a tragic view of modernity in which this is impossible: industrial society, powered by flaming carbon, contains the fuel of its own destruction. But the tragic view is incorrect. Ausubel notes that the modern world has been progressively *de*carbonizing.

The hydrocarbons in the stuff we burn are composed of hydrogen and carbon, which release energy as they combine with oxygen to form

H_2O and CO_2. The oldest hydrocarbon fuel, dry wood, has a ratio of combustible carbon atoms to hydrogen atoms of about 10 to 1.[66] The coal which replaced it during the Industrial Revolution has an average carbon-to-hydrogen ratio of 2 to 1.[67] A petroleum fuel such as kerosene may have a ratio of 1 to 2. Natural gas is composed mainly of methane, whose chemical formula is CH_4, with a ratio of 1 to 4.[68] So as the industrial world climbed an energy ladder from wood to coal to oil to gas (the last transition accelerated in the 21st century by the abundance of shale gas from fracking), the ratio of carbon to hydrogen in its energy source steadily fell, and so did the amount of carbon that had to be burned to release a unit of energy (from 30 kg of carbon per gigajoule in 1850 to about 15 today).[69] Figure 10-7 shows that carbon emissions follow a Kuznets arc: when rich countries such as the United States and the United Kingdom first industrialized, they emitted more and more CO_2 to produce a dollar of GDP, but they turned a corner in the 1950s and since then have been emitting less and less. China and India are following suit, cresting in the late 1970s and mid-1990s, respectively. (China flew off the charts in the late 1950s because of Mao's boneheaded schemes like backyard iron smelters with copious emissions and zero economic output.) Carbon intensity for the world as a whole has been declining for half a century.[70]

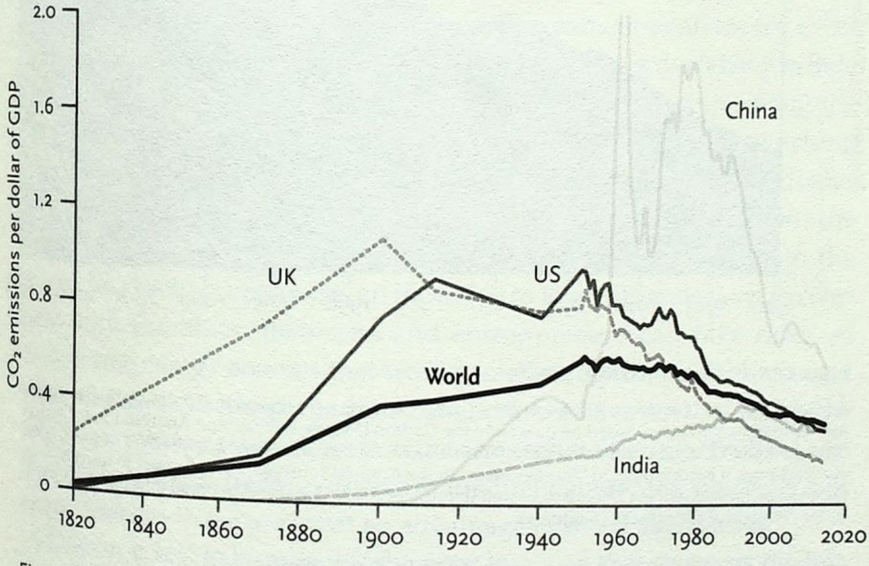

Figure 10-7: Carbon intensity (CO_2 emissions per dollar of GDP), 1820–2014

Source: Ritchie & Roser 2017, based on data from the Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/trends/emis/tre_coun.html. GDP is in 2011 international dollars; for the years before 1990, GDP comes from Maddison Project 2014.

Decarbonization is a natural consequence of people's preferences. "Carbon blackens miners' lungs, endangers urban air, and threatens climate change," Ausubel explains. "Hydrogen is as innocent as an element can be, ending combustion as water."[71] People want their energy dense and clean, and as they move into cities, they accept only electricity and gas, delivered right to their bedside and stovetop. Remarkably, this natural development has brought the world to Peak Coal and maybe even Peak Carbon. As figure 10-8 shows, global emissions plateaued from 2014 to 2015 and declined among the top three emitters, namely China, the European Union, and the United States. (As we saw for the United States in figure 10-3, carbon emissions plateaued while prosperity rose: between 2014 and 2016, the Gross World Product grew by 3 percent annually.)[72] Some of the carbon was reduced by the growth of wind and solar power, but most of it, particularly in the United States, was reduced by the replacement of $C_{137}H_{97}O_9NS$ coal with CH_4 gas.

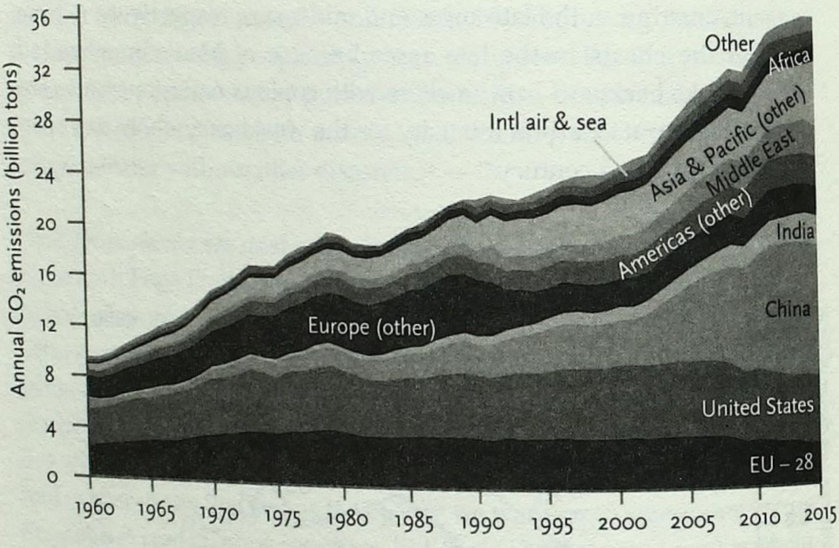

Figure 10-8: CO_2 emissions, 1960–2015

Sources: *Our World in Data*, Ritchie & Roser 2017 and https://ourworldindata.org/grapher/annual-co2-emissions-by-region, based on data from the Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/CO2_Emission/, and Le Quéré et al. 2016. "International air & sea" refers to aviation and sea transport; it corresponds to "Bunker fuels" in the original sources. "Other" refers to the difference between estimated global CO_2 emissions and the sum of the regional and national totals; it corresponds to the "Statistical difference" component.

The long sweep of decarbonization shows that economic growth is not synonymous with burning carbon. Some optimists believe that if the trend is allowed to evolve into its next phase—from low-carbon natural gas to zero-carbon nuclear energy, a process abbreviated as "N2N"—the climate will have a soft landing. But only the sunniest believe this will happen by itself. Annual CO_2 emissions may have leveled off for the time being at around 36 billion tons, but that's still a *lot* of CO_2 added to the atmosphere every year, and there is no sign of the precipitous plunge we would need to stave off the harmful outcomes. Instead, decarbonization needs to be helped along with pushes from policy and technology, an idea called deep decarbonization.[73]

It begins with carbon pricing: charging people and companies for the damage they do when they dump their carbon into the atmosphere, either as a tax on carbon or as a national cap with tradeable credits. Economists across the political spectrum endorse carbon pricing because it combines the unique advantages of governments and markets.[74] No one owns the atmosphere, so people (and companies) have no reason to stint on emissions that allow each of them to enjoy their energy while harming everyone else, a perverse outcome that economists call a negative externality (another name for the collective costs in a public goods game, or the damage to the commons in the Tragedy of the Commons). A carbon tax, which only governments can impose, "internalizes" the public costs, forcing people to factor the harm into every carbon-emitting decision they make. Having billions of people decide how best to conserve, given their values and the information conveyed by prices, is bound to be more efficient and humane than having government analysts try to divine the optimal mixture from their desks. The potters don't have to hide their kilns from the Carbon Police; they can do their part in saving the planet by taking shorter showers, forgoing Sunday drives, and switching from beef to eggplant. Parents don't have to calculate whether diaper services, with their trucks and laundries, emit more carbon than the makers of disposable diapers; the difference will be folded into the prices, and each company has an incentive to lower its emissions to compete with the other. Inventors and entrepreneurs can take risks on carbon-free energy sources that would compete against fossil fuels on a level playing field rather than the tilted one we have now, in which the fossils get to spew their waste into the atmosphere for free. Without carbon pricing, fossil fuels—which are uniquely abundant, portable, and energy-dense—have too great an advantage over the alternatives.

Carbon taxes, to be sure, hit the poor in a way that concerns the left, and they transfer money from the private to the public sector in a way that annoys the right. But these effects can be neutralized by adjusting sales, payroll, income, and other taxes and transfers. (As Al Gore put it:

Tax what you burn, not what you earn.) And if the tax starts low and increases steeply and predictably over time, people can factor the increase into their long-term purchases and investments, and by favoring low-carbon technologies as they evolve, escape most of the tax altogether.[75]

A second key to deep decarbonization brings up an inconvenient truth for the traditional Green movement: nuclear power is the world's most abundant and scalable carbon-free energy source.[76] Although renewable energy sources, particularly solar and wind, have become drastically cheaper, and their share of the world's energy has more than tripled in the past five years, that share is still a paltry 1.5 percent, and there are limits on how high it can go.[77] The wind is often becalmed, and the sun sets every night and may be clouded over. But people need energy around the clock, rain or shine. Batteries that could store and release large amounts of energy from renewables will help, but ones that could work on the scale of cities are years away. Also, wind and solar sprawl over vast acreage, defying the densification process that is friendliest to the environment. The energy analyst Robert Bryce estimates that simply keeping up with the world's increase in energy use would require turning an area the size of Germany into wind farms every year.[78] To satisfy the world's needs with renewables by 2050 would require tiling windmills and solar panels over an area the size of the United States (including Alaska), plus Mexico, Central America, and the inhabited portion of Canada.[79]

Nuclear energy, in contrast, represents the ultimate in density, because, in a nuclear reaction, $E = mc^2$: you get an immense amount of energy (proportional to the speed of light squared) from a small bit of mass. Mining the uranium for nuclear energy leaves a far smaller environmental scar than mining coal, oil, or gas, and the power plants themselves take up about one five-hundredth of the land needed by wind or solar.[80] Nuclear energy is available around the clock, and it can be plugged into power grids that provide concentrated energy where it is needed. It has a lower carbon footprint than solar, hydro, and biomass, and it's safer than them, too. The sixty years with nuclear power have seen thirty-one deaths in the 1986 Chernobyl disaster, the result of extraordinary Soviet-era bungling, together with a few thousand early deaths from cancer above the 100,000 natural cancer deaths in the exposed population.[81] The other two famous accidents, at Three Mile Island in 1979 and Fukushima in 2011, killed no one. Yet vast numbers of people are killed day in, day out by the pollution from burning combustibles and by accidents in mining and transporting them, none of which make headlines. Compared with nuclear power, natural gas kills 38 times as many people per kilowatt-hour of electricity generated, biomass 63 times as many, petroleum 243 times as many, and coal *387* times as many—perhaps a million deaths a year.[82]

Nordhaus and Shellenberger summarize the calculations of an increasing number of climate scientists: "There is no credible path to reducing global carbon emissions without an enormous expansion of nuclear power. It is the only low carbon technology we have today with the demonstrated capability to generate large quantities of centrally generated electric power."[83] The Deep Carbonization Pathways Project, a consortium of research teams that have worked out roadmaps for countries to reduce their emissions enough to meet the 2°C target, estimates that the United States will have to get between 30 and 60 percent of its electricity from nuclear power by 2050 (1.5 to 3 times the current fraction), at the same time that it generates far more of that electricity to take over from fossil fuels in heating homes, powering vehicles, and producing steel, cement, and fertilizer.[84] In one scenario, this would require quadrupling its nuclear capacity. Similar expansions would be necessary in China, Russia, and other countries.[85]

Unfortunately, the use of nuclear power has been shrinking just when it should be growing. In the United States, eleven nuclear reactors have recently been closed or are threatened with closure, which would cancel the entire carbon savings from the expanded use of solar and wind. Germany, which has relied on nuclear energy for much of its electricity, is shutting down its plants as well, increasing its carbon emissions from the coal-fired plants that replace them, and France and Japan may follow its lead.

Why are Western countries going the wrong way? Nuclear power presses a number of psychological buttons—fear of poisoning, ease of imagining catastrophes, distrust of the unfamiliar and the man-made—and the dread has been amplified by the traditional Green movement and its dubiously "progressive" supporters.[86] One commentator blames global warming on the Doobie Brothers, Bonnie Raitt, and the other rock stars whose 1979 *No Nukes* concert and film galvanized baby-boomer sentiment against nuclear power. (Sample lyrics of the closing anthem: "Just give me the warm power of the sun . . . But won't you take all your atomic poison power away.")[87] Some of the blame might go to Jane Fonda, Michael Douglas, and the producers of the 1979 disaster film *The China Syndrome*, so named because the melted-down nuclear reactor core would supposedly sink through the Earth's crust all the way to China, after making "an area the size of Pennsylvania" uninhabitable. In a devilish coincidence, the Three Mile Island plant in central Pennsylvania suffered its partial meltdown two weeks after the movie's release, creating widespread panic and making the very idea of nuclear power as radioactive as its uranium fuel.

It's often said that with climate change, those who know the most are the most frightened, but with nuclear power, those who know the most are the least frightened.[88] As with oil tankers, cars, planes, buildings, and factories (chapter 12), engineers have learned from the accidents and near-misses and have progressively squeezed more safety out of nuclear reactors, reducing the risks of accidents and contamination far below those of fossil fuels. The advantage even extends to radioactivity, which is a natural property of the fly ash and flue gases emitted by burning coal.

Still, nuclear power is expensive, mainly because it must clear crippling regulatory hurdles while its competitors have been given easy passage. Also, in the United States, nuclear power plants are now being built, after a lengthy hiatus, by private companies using idiosyncratic designs, so they have not climbed the engineer's learning curve and settled on the best practices in design, fabrication, and construction. Sweden, France, and South Korea, in contrast, have built standardized reactors by the dozen and now enjoy cheap electricity with substantially lower carbon emissions. As Ivan Selin, former commissioner of the Nuclear Regulatory Commission, put it, "The French have two kinds of reactors and hundreds of kinds of cheese, whereas in the United States the figures are reversed."[89]

For nuclear power to play a transformative role in decarbonization it will eventually have to leap past the second-generation technology of light-water reactors. (The "first generation" consisted of prototypes from the 1950s and early 1960s.) Soon to come on line are a few Generation III reactors, which evolved from the current designs with improvements in safety and efficiency but so far have been plagued by financial and construction snafus. Generation IV reactors comprise a half-dozen new designs which promise to make nuclear plants a mass-produced commodity rather than finicky limited editions.[90] One type might be cranked out on an assembly line like jet engines, fitted into shipping containers, transported by rail, and installed on barges anchored offshore cities. This would allow them to clear the NIMBY hurdle, ride out storms or tsunamis, and be towed away at the end of their useful lives for decommissioning. Depending on the design, they could be buried and operated underground, cooled by inert gas or molten salt that needn't be pressurized, refueled continuously with a stream of pebbles rather than shut down for the replacement of fuel rods, equipped to co-generate hydrogen (the cleanest of fuels), and designed to shut themselves off without power or human intervention if they overheat. Some would be fueled by relatively abundant thorium, and others by uranium extracted from seawater, from dismantled nuclear weapons (the ultimate beating of swords into plowshares), from the waste of existing reactors, or even from their own waste—the closest we will ever get to a perpetual-motion machine, capable of powering the world for thousands of years. Even nuclear fusion, long derided as the energy source that is "thirty years away and always will be," really may be thirty years away (or less) this time.[91]

The benefits of advanced nuclear energy are incalculable. Most climate change efforts call for policy reforms (such as carbon pricing) which remain contentious and will be hard to implement worldwide even in the rosiest scenarios. An energy source that is cheaper, denser, and cleaner than fossil fuels would sell itself, requiring no herculean political will or international cooperation.[92] It would not just mitigate climate change but furnish manifold other gifts. People in the developing world could skip the middle rungs in the energy ladder, bringing their standard of living up to that of the West without choking on coal smoke. Affordable desalination of seawater, an energy-ravenous process, could irrigate farms, supply drinking water, and, by reducing the need for both surface water and hydro power, allow dams to be dismantled, restoring the flow of rivers to lakes and seas and revivifying entire ecosystems. The team that brings clean and abundant energy to the world will benefit humanity more than all of history's saints, heroes, prophets, martyrs, and laureates combined.

Breakthroughs in energy may come from startups founded by idealistic inventors, from the skunk works of energy companies, or from the vanity projects of tech billionaires, especially if they have a diversified portfolio of safe bets and crazy moonshots.[93] But research and development will also need a boost from governments, because these global public goods are too great a risk with too little reward for private companies. Governments must play a role because, as Brand points out, "infrastructure is one of the things we hire governments to handle, especially energy infrastructure, which requires no end of legislation, bonds, rights of way, regulations, subsidies, research, and public-private contracts with detailed oversight."[94] This includes a regulatory environment that is suited to 21st-century challenges rather than to 1970s-era technophobia and nuclear dread. Some fourth-generation nuclear technologies are shovel-ready, but are trussed in regulatory green tape and may never see the light of day, at least not in the United States.[95] China, Russia, India, and Indonesia, which are hungry for energy, sick of smog, and free from American squeamishness and political gridlock, may take the lead.

Whoever does it, and whichever fuel they use, the success of deep decarbonization will hinge on technological progress. Why assume that the know-how of 2018 is the best the world can do? Decarbonization will need breakthroughs not just in nuclear power but on other technological frontiers: batteries to store the intermittent energy from renewables; Internet-like smart grids that distribute electricity from scattered sources to scattered users at scattered times; technologies that electrify and decarbonize industrial processes such as the production of cement, fertilizer, and steel; liquid biofuels for heavy trucks and planes that need dense, portable energy; and methods of capturing and storing CO_2.

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The last of these is critical for a simple reason. Even if greenhouse gas emissions are halved by 2050 and zeroed by 2075, the world would still be on course for risky warming, because the CO_2 already emitted will remain in the atmosphere for a very long time. It's not enough to stop thickening the greenhouse; at some point we have to dismantle it.

The basic technology is more than a billion years old. Plants suck carbon out of the air as they use the energy in sunlight to combine CO_2 with H_2O and make sugars (like $C_6H_{12}O_6$), cellulose (a chain of $C_6H_{10}O_5$ units), and lignin (a chain of units like $C_{10}H_{14}O_4$); the latter two make up most of the biomass in wood and stems. The obvious way to remove CO_2 from the air, then, is to recruit as many carbon-hungry plants as we can to help us. We can do this by encouraging the transition from deforestation to reforestation and afforestation (planting new forests), by reversing tillage and wetland destruction, and by restoring coastal and marine habitats. And to reduce the amount of carbon that returns to the atmosphere when dead plants rot, we could encourage building with wood and other plant products, or cook the biomass into non-rotting charcoal and bury it as a soil amendment called biochar.[96]

Other ideas for carbon capture span a broad range of flakiness, at least by the standards of current technology. The more speculative end shades into geoengineering, and includes plans to disperse pulverized rock that takes up CO_2 as it weathers, to add alkali to clouds or the oceans to dissolve more CO_2 in water, and to fertilize the ocean with iron to accelerate photosynthesis by plankton.[97] The more proven end consists of technologies that can scrub CO_2 from the smokestacks of fossil fuel plants and pump it into nooks and crannies in the earth's crust. (Skimming the sparse 400 parts per million directly from the atmosphere is theoretically possible but prohibitively inefficient, though that could change if nuclear power became cheap enough.) The technologies can be retrofitted into existing factories and power plants, and though they are themselves energy-hungry, they could slash carbon emissions from the vast energy infrastructure that is already in place (resulting in so-called clean coal). The technologies can also be fitted onto gasification plants that convert coal into liquid fuels, which may still be needed for planes and heavy trucks. The geophysicist Daniel Schrag points out that the gasification process already has to separate CO_2 from the gas stream, so sequestering that CO_2 to protect the atmosphere is a modest incremental expense, and it would yield liquid fuel with a smaller carbon footprint than that of petroleum.[98] Better still, if the coal feedstock is supplemented with biomass (including grasses, agricultural waste, forest cuttings, municipal garbage, and perhaps someday genetically engineered plants or algae), it could be carbon-neutral. Best of all, if the feedstock consisted *exclusively* of biomass, it would be carbon-*negative*. The plants pull CO_2 out of the atmosphere, and when their biomass is used for energy (via combustion, fermentation, or gasification), the carbon capture process keeps it out. The combination, sometimes called BECCS—bioenergy with carbon capture and storage—has been called climate change's savior technology.[99]

Will any of this happen? The obstacles are unnerving; they include the world's growing thirst for energy, the convenience of fossil fuels with their vast infrastructure, the denial of the problem by energy corporations and the political right, the hostility to technological solutions from traditional Greens and the climate justice left, and the tragedy of the carbon commons. For all that, preventing climate change is an idea whose time has come. One indication is a trio of headlines that appeared in *Time* magazine within a three-week span in 2015: "China Shows It's Serious About Climate Change," "Walmart, McDonald's, and 79 Others Commit to Fight Global Warming," and "Americans' Denial of Climate Change Hits Record Low." In the same season the *New York Times* reported, "Poll Finds Global Consensus on a Need to Tackle Climate Change." In all but one of the forty countries surveyed (Pakistan), a majority of respondents were in favor of limiting greenhouse gas emissions, including 69 percent of the Americans.[100]

The global consensus is not just hot air. In December 2015, 195 countries signed a historic agreement that committed them to keeping the global temperature rise to "well below" 2°C (with a target of 1.5°C) and to setting aside $100 billion annually in climate mitigation financing for developing countries (which had been a sticking point in prior, unsuccessful attempts at a global consensus).[101] In October 2016, 115 of the signatories ratified the agreement, putting it into force. Most of the signatories submitted detailed plans on how they would pursue these goals through 2025, and all promised to update their plans every five years with stepped-up efforts. Without this ratcheting, the current plans are inadequate: they would allow the world's temperature to rise by 2.7°C, and would reduce the chance of a dangerous 4°C rise in 2100 by only 75 percent, which is still too close for comfort. But the public commitments, combined with contagious technological advances, could push the ratchet upward, in which case the Paris agreement would substantially reduce the likelihood of a 2°C rise and essentially eliminate the possibility of a 4°C rise.[102]

This game plan faced a setback in 2017 when Donald Trump, who had notoriously called climate change a Chinese hoax, announced that the United States would withdraw from the agreement. Even if the withdrawal takes place in November 2020 (the earliest possible date), the decarbonization driven by technology and economics will continue, and climate change policies will be advanced by cities, states, business and tech leaders, and the world's other countries, which have declared the deal "irreversible" and may pressure the United States to keep its word by imposing carbon tariffs on American exports and other sanctions.[103]

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Even with fair winds and following seas, the effort needed to prevent climate change is immense, and we have no guarantee that the necessary transformations in technology and politics will be in place soon enough to slow down global warming before it causes extensive harm. This brings us to a last-ditch protective measure: lowering the world's temperature by reducing the amount of solar radiation that reaches the lower atmosphere and Earth's surface.[104] A fleet of airplanes could spray a fine mist of sulfates, calcite, or nanoparticles into the stratosphere, spreading a thin veil that would reflect back just enough sunlight to prevent dangerous warming.[105] This would mimic the effects of a volcanic eruption such as that of Mount Pinatubo in the Philippines in 1991, which spewed so much sulfur dioxide into the atmosphere that the planet cooled down by half a degree Celsius (about one degree Fahrenheit) for two years. Or a fleet of cloudships could spray a fine mist of seawater into the air. As the water evaporated, salt crystals would waft into the clouds and water vapor would condense around them, forming droplets that would whiten the clouds and reflect more sunlight back into space. These measures are relatively inexpensive, require no exotic new technologies, and could bring global temperatures down quickly. Other ideas for manipulating the atmosphere and oceans have been bruited about as well, though research on all of them is in its infancy.

The very idea of climate engineering sounds like the crazed scheme of a mad scientist, and it once was close to taboo. Critics see it as a Promethean folly that could have unintended consequences such as disrupting rainfall patterns and damaging the ozone layer. Since the effects of any measure applied to the entire planet are uneven from place to place, climate engineering raises the question of whose hand should be on the world's thermostat: as with a bickering couple, if one country lowered the temperature at the expense of another, it could set off a war. Once the world depended on climate engineering, then if for any reason it slacked off, temperatures in the carbon-soaked atmosphere would soar far more quickly than people could adapt. The mere mention of an escape hatch for the climate crisis creates a moral hazard, tempting countries to shirk their duty to reduce greenhouse gas emissions. And the accumulated CO_2 in the atmosphere would continue to dissolve in seawater, slowly turning the oceans into carbonic acid.

For all these reasons, no responsible person could maintain that we can just keep pumping carbon into the air and slather sunscreen onto the stratosphere to compensate. But in a 2013 book the physicist David Keith makes a case for a form of climate engineering that is *moderate, responsive,* and *temporary.* "Moderate" means that the amounts of sulfate or calcite would be just enough to reduce the rate of warming, not cancel it altogether; moderation is a virtue because small manipulations are less likely to bring unwelcome surprises. "Responsive" means that any manipulation would be careful, gradual, closely monitored, constantly adjusted, and, if indicated, halted altogether. And "temporary" means that the program would be designed only to give humanity breathing space until it eliminates greenhouse gas emissions and brings the CO_2 in the atmosphere back to preindustrial levels. In response to the fear that the world would become addicted to climate engineering forever, Keith remarks, "Is it plausible that we will not figure out how to pull, say, five gigatons of carbon per year out of the air by 2075? I don't buy it."[106]

Though Keith is among the world's foremost climate engineers, he cannot be accused of being carried away by innovation thrill. A similarly thoughtful case may be found in the journalist Oliver Morton's 2015 book *The Planet Remade,* which presents the historical, political, and moral dimensions of climate engineering alongside the technical state of the art. Morton shows that humanity has been disrupting global cycles of water, nitrogen, and carbon for more than a century, so it's too late to preserve a primeval Earth system. And given the enormity of the climate change problem, it's unwise to assume we will solve it quickly or easily. Research into how we might minimize the harm to millions of people before the solutions are completely in place only seems prudent, and Morton lays out scenarios of how a program of moderate and temporary climate engineering might be implemented even in a world that falls short of ideal global governance. The legal scholar Dan Kahan has shown that far from creating a moral hazard, providing information about climate engineering makes people *more* concerned about climate change and less biased by their political ideology.[107]

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Despite a half-century of panic, humanity is not on an irrevocable path to ecological suicide. The fear of resource shortages is misconceived. So is the misanthropic environmentalism that sees modern humans as vile despoilers of a pristine planet. An enlightened environmentalism recognizes that humans need to use energy to lift themselves out of the poverty to which entropy and evolution consign them. It seeks the means to do so with the least harm to the planet and the living world. History suggests that this modern, pragmatic, and humanistic environmentalism can work. As the world gets richer and more tech-savvy, it dematerializes, decarbonizes, and densifies, sparing land and species. As people get richer and better educated, they care more about the environment, figure out ways to protect it, and are better able to pay the costs. Many parts of the environment are rebounding, emboldening us to deal with the admittedly severe problems that remain.

First among them is the emission of greenhouse gases and the threat they pose of dangerous climate change. People sometimes ask me whether I think that humanity will rise to the challenge or whether we will sit back and let disaster unfold. For what it's worth, I think we'll rise to the challenge, but it's vital to understand the nature of this optimism. The economist Paul Romer distinguishes between *complacent* optimism, the feeling of a child waiting for presents on Christmas morning, and *conditional* optimism, the feeling of a child who wants a treehouse and realizes that if he gets some wood and nails and persuades other kids to help him, he can build one.[108] We cannot be complacently optimistic about climate change, but we can be conditionally optimistic. We have some practicable ways to prevent the harms and we have the means to learn more. Problems are solvable. That does not mean that they will solve themselves, but it does mean that we can solve them *if* we sustain the benevolent forces of modernity that have allowed us to solve problems so far, including societal prosperity, wisely regulated markets, international governance, and investments in science and technology.