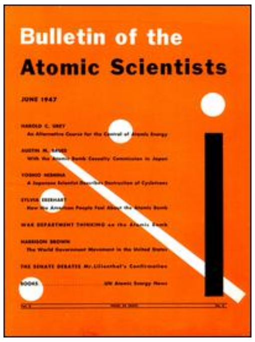

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Contending with climate change: The next 25 years

Robert H. Socolow

ABSTRACT
Any successful effort to address climate change over the next 25 years will involve a "credible swap" that greatly reduces greenhouse gas emissions from the burning of fossil fuels, provides energy in entirely different ways, and also reduces demand for energy. On the demand side, the next quarter century offers abundant high-leverage opportunities to reduce future emissions via intelligent urban design, building construction (notably in the gigantic apartment complexes), and efficient vehicles and appliances. On the supply side, there are three variants of the swap. In one, the work horse is renewable energy (solar power, wind power, hydropower, and power from biological feedstocks); in a second it is nuclear power; and in a third it is a reshaped fossil fuel economy. The three are by no means mutually exclusive. Each brings disruption and risks, rivaling those of climate change if done inattentively. Well-executed solutions will require threading a needle.

KEYWORDS
Climate change; energy efficiency; Paris Accord; renewable energy; nuclear energy; carbon dioxide capture; collective destiny

The centennials of Hiroshima, Nagasaki, and the founding of the *Bulletin of the Atomic Scientists* are only 25 years ahead. When I think about the next 25 years, I see the people of this planet wrestling with a reality that has only recently emerged. For the first time in human history, we human beings, doing ordinary things, can alter our entire planet in ways that are harmful to ourselves. And every available strategy to work around these limitations is fraught, so we need to be clever and clearheaded and wary. Fitting on our planet, rather than bursting its seams, is going to be difficult. It will preoccupy many successive generations.

Climate is one of many examples of potential seam-bursting – others include arable land and fisheries – but climate is the one I have thought most about. We are vulnerable to environmental disruption because what makes us distinctly human is finely tuned to a planet that has been quite stable. An apt example is sea level. During Earth's exit from the most recent ice age, from approximately 14,000 to 6,000 years ago, sea level rose 130 meters. But it has changed very little during the past six millennia, with the result that many of the world's cities have been built at the edge of an unchanging sea. A mere two meters of sea level rise would require extensive changes to these cities and abandonment of some of them.

The largest agent of the climate portion of our newly challenging reality is the carbon dioxide that results when we burn fossil fuels. Because of their high energy density, it is economic to move fossil fuels over global distances by rail and ship and pipeline, enabling global markets. Costs are modest because the best geological sources are highly concentrated: thick seams of coal and expansive reservoirs of oil and natural gas. And the fossil fuels are abundant, in the sense that they could meet the world's energy needs for centuries (although probably not for millennia).

Indeed, there would be little pressure today to move away from a global economy based on fossil fuels if it weren't for their Achilles heel. The carbon dioxide created by burning fossil fuels has routinely been sent to the atmosphere, where, we now appreciate, it has a potent role in driving climate. The Earth cools off to space via infrared radiation at wavelengths where nitrogen, oxygen, and argon are essentially transparent. As a result, three-atom molecules dominate the cooling process, and of these, carbon dioxide is second only to water vapor in its importance. Nasty climate impacts are showing up already, and impacts will get worse.

We are only just beginning to scope the modifications of currently dominant practices that we will need to pursue on a planetary scale over many decades in order to sustain our well-being (Pacala and Socolow 2004; Socolow 2011). Our collective assignment in the energy domain is to swap out fossil fuel use everywhere. A major political instrument is the 2015 Paris Accord. The objective it establishes, in effect, requires cutting global carbon dioxide emissions approximately in half over the next 25 years. In turn, this requires lowering the per capita emissions in the industrialized countries to the current level in the less developed countries, while the less developed countries figure

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out how to industrialize without adding to their own emissions. To those who wish "fairness" to take the form of prolonged rising emissions trajectories in developing countries that mimic those of the countries that industrialized on the backs of coal and petroleum half a century and more ago, the message is unpleasant: Safe is not fair, and fair is not safe (Tavoni, Chakravarty, and Socolow 2012).

The Paris Accord is a recurrent pot-luck dinner. Each country comes with its best dish – some carbon-relevant initiative like a build-out of electric vehicles or a carbon tax or a reforestation measure – and the other countries inspect it. They are supportive. (No one makes fun of a collapsed cake.) Every country looks at the other offerings and thinks, I could try to show off *that* dish when I come back in five years. The Paris Accord is brilliant diplomacy, designed to create a race to the top. Tough targets are motivating governments and industry to start decarbonizing. Of course, the first offerings aren't that impressive, but a path forward, at least for the next 25 years, has been created. It could work.

One problem with the potluck-dinner metaphor is that it leaves out the cross-national role of civil society, whose independent evaluations of national offerings constitute another important part of the Paris process. If a country brings forward a dish that is not what it seems – whether as a result of deliberate deception or self-deception – the diplomats are counting on external critics to step in.

The swap ahead

Any credible swap for the burning of fossil fuels must not only provide energy in entirely different ways but must also reduce demand. Jointly realized, the result is an energy-efficient electric car and solar panels on a well-insulated roof. Because most of the upward pressure on global energy demand over the next 25 years will result from investments in industrializing countries, largely in their fast-growing cities, high leverage is inherent in intelligent urban design, building construction (notably in the gigantic apartment complexes), and efficient vehicles and appliances. A general rule is that efficiency is much more easily accomplished at the time of initial construction of infrastructure and energy-consuming facilities than via retrofits later on. Thus, the next quarter century represents a fleeting interval during which there will be abundant high-leverage opportunities to reduce future emissions.

Alas, the literature of energy efficiency is dominated by studies of why the potential of various attractive investments is not realized. The shortfall is attributed to split incentives between builder and occupant, lack of trust in a sales pitch, minimal psychic payoff, and other misalignments. Efficiency, moreover, is rarely gained without trading away at least a little of other attributes that matter: safety, convenience, comfort, and privacy come to mind. Artful improvements that lower energy use are like boulders in a road – in plain sight but devilishly difficult to move. Over the next 25 years, however, if there is an overhaul of energy supply, it seems nearly certain that there will be comparably substantial shifts in the technologies and behaviors that determine energy demand.

On the supply side, there are three variants of the swap, depending on the dominant low-carbon energy source. In one variant, the workhorse is renewable energy (primarily, solar power, wind power, hydropower, and power from biological feedstocks); in a second it is nuclear power; and in a third it is a reshaped fossil fuel economy. The three are by no means mutually exclusive. Each brings its own disruption and risks, rivaling those of climate change if done inattentively (Socolow 2020). Well-executed solutions are like threading a needle, as I will explain.

Renewable energy (solar power, wind power, hydropower, and power from biological feedstocks)

One strong streak within environmentalism, its greenest streak, places a priority on protecting land from industrialization and even from human intrusion. The results range from neighborhood conservation easements, to free-running streams, to safe habitats for endangered species, to designated wilderness areas and national parks on public land, to "unspoiled" views. My own first project as an environmental analyst in the early 1970s led to the rejection of an international airport threatening the Florida Everglades (Harte and Socolow 1971). My second led to the cancellation of a main-stem dam on the Delaware River that would have adversely affected shad and oysters and would have replaced kayaks with motorboats (Socolow, Feiveson, and Sinden 1976). All the renewable energy options are land-intensive. What sort of reception will they get?

Well, dam-building has all but stopped in the United States, but not on the Blue Nile in Ethiopia and elsewhere in developing countries. Growing biomass crops for energy has had a checkered record; sugarcane for ethanol in Brazil and corn for ethanol in the Midwest of the United States have been less controversial energy sources than Indonesian palm oil and wood chips from southeastern United States forests. Multimillion-panel solar fields are spreading across the deserts of the United States and China, at the same time as many environmentalists push for and much prefer "distributed" solar power on rooftops and in farmers' fields. Wind turbines have been welcomed in Iowa but a decade ago they were rejected off Cape Cod.

The tension may be subsiding. I have the impression that wind turbines are now increasingly seen as beautiful, or at least not as eyesores. Nonetheless, over the next 25 years, I expect the siting of renewable energy to be constantly and widely contested by those arguing on behalf of traditional environmental values.

The most notable development in the past quarter century bearing on solutions to climate change has been the much increased competitiveness of solar and wind power. The cost of a solar panel fell by about 20 percent for each doubling of cumulative panel production – for 20 doublings! The physicist, seeking a "zeroth-order" view of solar power, can "assume" a free panel and turn her attention to grid integration. Indeed, she will find that the full costs are understated when estimated in the usual way as the "levelized cost" of electricity, which is the annualized total cost of a project divided by the quantity of electricity generated in a year. This ratio is oblivious to the fact that wind and solar electricity are not at our beck and call (are not "dispatchable"), while many alternatives are.

Over the next 25 years, adaptation to the variability of wind and solar power will be central to the climate change mitigation agenda. Consumers will do their part: For example, electric vehicles will be charged on sunny days at noon, spurred by smart pricing. Power engineers, trained to assure that the consumer of electricity is unaware of whether the day is sunny or cloudy or windy or calm, will think initially of supplementary power and batteries, but over the next 25 years, I think their system goal will be revised.

Nuclear energy

Half a century ago, nuclear power was the presumed future for electricity. In the United States, roughly one thousand large (1,000 megawatt) reactors by 2000 was the planning horizon. Deployment plateaued at 100. Global deployment plateaued at 400. One nuclear renaissance after another has turned out to be a mirage, and many energy experts are convinced that a downward glide over the next 25 years is inevitable.

But I am not convinced. The current high cost of new nuclear power reflects, at least in part, a loss of momentum in the United States, France, and Japan, the three countries which led the first round of nuclear power plant construction. It seems credible that the low-carbon agenda will elicit high-volume construction and falling costs for large reactors, which will then be marketed all over the world, mostly from China, South Korea, and Russia.

If there is a major expansion of nuclear power worldwide, to what extent will the capability to build nuclear weapons grow as well? For many of the recipient countries, achieving such a capability could be at least as strong a motivation to acquire nuclear power plants as meeting some low-carbon objective. Climate change provides cover, for which it is worth payng a premium.

In short, nuclear power links climate change to nuclear war (Socolow and Glaser 2009). The more compelling the link between climate change and nuclear power, the more critical it is to disable the link between nuclear power and nuclear war. The next 25 years, and indeed the next decade, may represent the last opportunity to strengthen the international arrangements for the management of the nuclear fuel cycle, so that neither uranium isotope enrichment nor the treatment of plutonium in spent fuel can be conducted in ways that enable national nuclear weapons programs. I have no more fervent hope than that the world finds a path to nuclear sanity without first requiring a "lesson" where some political argument escalates and these weapons are used.

Four deficiencies today inhibit progress. 1) The global nuclear power industry is unwilling to concede the salience of the link between nuclear power and nuclear weapons; "the genie is out of the bottle," they say. 2) The climate change community expunges "nuclear" from all discourse, so that, for example, the interested citizen needs a glossary to figure out that "renewable energy" excludes nuclear power, but "low-carbon energy" does not. It is not there, if no one talks about it. 3) The current nuclear weapons states undermine the possibility of an effective global taboo on the use of nuclear weapons by investing heavily in "modernization" and "renovation" and, as well, by building missiles that can carry either nuclear or conventional warheads. 4) The younger generations have heard so little about nuclear weapons that they have concluded that these weapons must no longer be worth worrying about.

The extensive work of the *Bulletin* community over the past 75 years will provide accessible intellectual capital if nuclear power has a resurgence. Earlier insights will be retrieved, reevaluated, and brought up to date.

A reshaped fossil fuel economy

I have been intrigued for nearly 25 years by the possibility that the oil and gas industry could lead the way on climate-driven carbon management. If this does not happen, it will not be for technical reasons. The management skills required to overhaul the world's carbon-based energy system resemble those that the industry brings to bear in the implementation of its biggest projects. Arguably, neither the renewables industry nor the nuclear industry is matched to the task. The oil and gas industry has extensive experience with injecting fluids into geological formations deep below ground and with moving fluids above ground via pipelines and ships. A low-carbon energy system is highly likely to feature these tasks. Moreover, the oil and gas industry is concentrated in particular regions, where its political power and its popularity are formidable; a broader coalition is created when these regions are engaged.

At present, many oil and gas companies are saying that they wish to reinvent themselves as part of the solution, instead of part of the problem. Is it too late? For such shifts to be successful, there would need to be at least tacit support from the world's green organizations, whose priorities have been driving climate policy thus far and whose distrust of the fossil fuel industries is often deeply rooted. It will be hard for environmentalists to set aside the past disinformation campaigns of some of these companies conducted at a time when they already understood the connections between carbon dioxide and climate change as well as anyone.

Which might be specific roles for the oil and gas industry? Here are four. First, as wind power moves offshore to ever deeper water, it follows a progression already followed for oil and gas extraction, with platforms first built on the sea bottom and then floating. The value of the transfer of expertise is obvious to all involved parties. Second, the natural gas system currently backs up variable wind and solar power, enabling the matching of supply and demand on the grid; solar and wind power will grow more quickly if natural gas continues in this role. Yet the current natural gas system is a major emitter of methane and carbon dioxide. Eliminating nearly all methane emissions is a matter of good housekeeping. As for carbon dioxide emissions, these engage the third and fourth options.

The third option is to capture the carbon dioxide produced in the combustion of natural gas and to inject it into sedimentary formations deep below ground, similar to the formations from which oil and natural gas are extracted (Socolow 2005). The oil and gas industry would provide these return trips. Currently, this carbon dioxide is sent to the atmosphere, but the decision to burn the fuel and the choice of this destination are separate: The atmosphere and geological formations are alternative waste baskets for carbon dioxide. Over the next 25 years the industry would lay thousands of miles of carbon dioxide pipeline and drill tens of thousands of new holes. The fourth option is to filter carbon dioxide from the air and inject that carbon dioxide too into geological formations, compensating for fossil-fuel-based emissions by creating "negative carbon emissions."

Both the third and fourth options involve carbon dioxide capture from a gas mixture, its transport under pressure in pipelines, and its injection below ground. All of these steps have already been commercialized. But the effort envisioned in many low-carbon global scenarios is formidable; the global flow rate of managed carbon dioxide can be one to 10 billion tons per year. Assuming that the density of the high-pressure carbon dioxide is sixth-tenths that of water, the volumetric flow corresponding to just one billion tons per year is (in units that the oil industry uses) thirty million barrels a day, which is one and a half times the oil production and consumption rate in the United States, or one-third of current global flow. Thus, envision an industry comparable to the current oil and gas industry. Of course, absent enabling policy that penalizes carbon dioxide emissions, the atmosphere will always win out as the wastebasket of choice for the invisible hand of the market.

By the *Bulletin*'s 100th anniversary, assuming the energy system has been substantially decarbonized, carbon strategies using the deep subsurface may be contributing substantially to climate change mitigation.

Almost for certain, during the next 25 years, the role of electricity will grow, relative to direct combustion of fossil fuels in vehicles, boilers, and furnaces. As a result, whatever the mix of the three low-carbon supply strategies, countries will expand their electric transmission networks. In the United States, the construction of new infrastructure over the next quarter century, if climate change objectives are prioritized, will resemble the replacement of a piecemeal road system by a National Highway System, a multi-decade task that started in the 1950s.

Solar geoengineering

It may turn out that swapping out the current fossil fuel energy system goes quite slowly over the next 25 years, because of the current system's durable appeal to consumers and the many ways by which change can be thwarted. The carbon dioxide concentration of the planet would be nearing 500 parts per million, up from 415 today, rather than creeping slowly upward to more like 450. Over the same time period, the Earth may signal to us that it amplifies the effects of our greenhouse gas emissions much more than we hoped, bringing on considerably worse heat waves and a faster ice sheet retreat than the central estimates of today's models predict.

Under such circumstances, I would expect the allure of solar geoengineering to grow. The objective of solar geoengineering, also called solar radiation management, is to cancel the global warming brought by greenhouse gases by deliberately reflecting a higher fraction of incident sunlight, a cooling effect. One scheme would inject reflective particles into the stratosphere. The largest volcanic eruptions produce global cooling in this way, but only for a year or two. The idea here is to mimic a perpetual volcano.

On first hearing, and on second hearing, many laypeople find solar geoengineering preposterous, and they recoil from it. Some invoke the hubris of Icarus. I am reminded of an environmental slogan from decades ago: "We mustn't treat the Earth as if we have a spare." Critics of any proposal to manipulate the planet will require its advocates to demonstrate that the Earth will recover promptly if anything goes wrong. We don't understand our planet well enough yet to provide such assurance, except for minimal manipulations. Even minimal experiments, however, are proving hard to conduct, on the grounds that inevitably they will send humankind down a slippery slope.

Hundreds of social science articles are addressing geoengineering governance at this time, even as actual field experiments are more or less on hold. They ask, against what threats, presenting themselves at what level, should an intervention be approved? What would constitute a victory? How can rogue interventions be thwarted? Who decides? Using which criteria?

Religious arguments are also surfacing. My own view has been affected by *The Case Against Perfection*, by Michael Sandel, which addresses *genetic* engineering. Sandel cautions against its use to enhance the human species (prettier, taller, smarter). He argues that we will thereby lose the ability to savor the life we have been "gifted," as well as the random, the "unbidden" (Sandel 2009). Similarly, I fear, geoengineering, seeking to enhance our planet, will turn it into a zoo. We can already eliminate terrible genetic diseases, and conceivably we may develop the capacity to eliminate terrible heat waves. But in both instances, isn't there a point of fateful excess?

Over the next 25 years I expect the *Bulletin* to become a valued forum for a wide-ranging exchange of views on geoengineering, from clarifying technical details to questioning the circumstances, if any, where it should be pursued.

Environmental justice

Continuing indefinitely to live exactly as we do now is dangerous. But the status quo is far from a full description of the global situation. Rather, billions of people are not yet living like the most prosperous – and wish to do so. Moreover, the world is organized to make this transition possible – banks and schools and technology providers, for instance, are among the facilitators. Much of the world conceives economic growth as a single universal upward escalator carrying all the world's people, floor by floor, into "the good life," with a private car, opportunities for leisure travel, creature comforts like air conditioning, and food from everywhere. Because income and carbon dioxide emissions are highly correlated, the development escalator thus conceived brings ever greater global carbon dioxide emissions and adds more danger to the danger we are already in.

All this can be quantified. The world right now sends into the atmosphere about 35 billion tons of carbon dioxide each year, and there are about seven billion of us, so per capita emissions are five tons of carbon dioxide per year. About one billion of us, currently, are "high emitters," defined as individuals responsible for more than 10 tons of carbon dioxide emissions per year, i.e. roughly the per capita emissions rate of the European Union and twice the world average (Chakravarty et al. 2009; Chakravarty, Socolow, and Tavoni 2009). The members of this club include nearly all Americans (per capita annual emissions in the United States are 15 tons of carbon dioxide), but members live all over the world, and new recruits to the club today come mainly from Asia. Indeed, two high emitters, one living in a country with low per capita emissions and the other in a country with high per capita emissions, are likely to have similar lifestyles. Collectively, this club is currently responsible for a little more than half of global emissions.

I can imagine new versions of the good life taking hold, expressing what decades ago was called "voluntary simplicity." Young people, especially if they come from prosperous families, routinely cross-examine their future selves along these lines, wondering about getting off the acquisition escalator at an intermediate floor. In past generations, most of them have decided otherwise as they grew older. But the message of global constraints was much weaker then.

What about the 85 percent who are not high emitters? We can define "low emitters" as those emitting less than 2 tons per year, approximately the per capita emissions of Brazil. Low emitters are just over half of the world's individuals, and they account, in total, for about one-tenth of the world's emissions. Most of them live in villages in South Asia and Africa. The middle group, emitting between 2 and 10 tons per year are one-third of the world's people, responsible for one-third of the emissions.

A near eradication of global extreme poverty, essentially the first transition on the development escalator, should be achievable over the next 25 years. It might require additional carbon dioxide emissions by today's low emitters.

Where fossil fuels are the least costly alternative, this transition would be accelerated by gasoline for motorbikes, diesel engines for village industry, and liquid petroleum gas (LPG) for cooking. Influential participants in development assistance object to such transitions, however. They insist that there be no use of fossil fuels, so as to avoid locking in future emissions. To be sure, there are many settings where renewable energy alternatives (rooftop solar power, fuels from local biomass) provide the same benefits as fossil fuels at lower cost. But my point is this: Even in a world striving for drastic reductions in total emissions, there is ample room to be relatively lax about the emissions of the very poor. Even four billion low emitters raising their average emissions from 1 to 2 tons per year would create a bump in current global emissions of only about 10 percent.

Equity issues are also embedded in the distribution of the harms inflicted by climate change. They are preferentially visited upon those least capable of defending themselves: the world's poorest nations and the poorest people within each country. To be sure, not all impacts are regressive; the well-being of those living on expensive low-lying coastal land is also threatened. The poster child is Miami. But the world's poor generally cannot ride out storms in structurally reinforced homes, cannot escape intense heat with air conditioning, cannot outsmart droughts with irrigation. This means that investments in resilience over the next 25 years have the potential to do double duty by both improving the lives of the least fortunate and diminishing climate-induced havoc. Investments in education, health care, construction quality, insurance, and emergency warning systems all have this second dimension.

As for inequities in paying the costs for modifications of the energy system to mitigate climate change, these too need to be guarded against. Because energy costs are a larger fraction of the expenditures of poor people, any policy that simply imposes a flat tax on carbon emissions, for example, will be regressive. (It will also have higher impact on rural than urban people with the same income, will negatively impact trucking, and will have other differential implications.) Moreover, without vigilance, the subsidies for rooftop solar power will preferentially benefit the owners of large homes, and biorefineries that turn energy crops into vehicle fuel will be sited in low-income neighborhoods. Modifications to make low-carbon policy progressive are available, however. One widely discussed policy returns the entire revenue from a flat carbon tax in the form of equal payments to all citizens. Another, making use of what once was called a "Lifeline Rate," provides the first units of consumption of, say, electricity, at a reduced unit cost.

Climate science

Because of the high societal value of an improved understanding of impending risks, I hope and expect that 25 years from now the climate science enterprise will be much larger, more ambitious, and more explicitly contributing to risk management. There will be more instruments in space, in the oceans, in the ice, in the forests; new methods for manipulating large data sets to tease out natural variability and reveal trends; and, perhaps most important, greater cross-pollination with neighboring disciplines like physics, chemistry, fluid mechanics, and computer science.

Make no mistake: Climate science is on a sufficiently secure footing to underpin the current sense of urgency. We already know enough to attribute debilitating heat waves and rampant arctic ice melting to our own emissions. Even a linear worsening from a rising carbon dioxide concentration would strongly motivate determined action. But even more dangerous non-linear behavior of our planet is plausible and cries out for deeper assessment (Socolow 2020; Palmer and Stevens 2019).

To give a single example, our planet would be much hotter were it not for clouds that shield us somewhat from incoming sunlight. Our additions to atmospheric carbon dioxide and other greenhouse gases could get us into serious trouble if the result were to lead to an overall dissipation of clouds, which would produce a positive feedback leading to further warming. How clouds of various kinds respond to rising levels of atmospheric carbon dioxide is a problem on the frontier of climate science today.

Along with stronger climate science, I am fairly sure that the next 25 years will bring a more climate-literate citizenry, thanks to insertions of climate science into the curriculum from kindergarten through graduate school. Each year, I ask my college students why the Earth does not get hotter and hotter as the sun keeps shining on it. They could have learned the answer in sixth grade: The Earth cools off to outer space, which is very cold. By 10th grade they could have learned that certain gases in the atmosphere, especially carbon dioxide, inhibit this cooling mechanism and make our planet's surface hotter. Curriculum reform usually requires a shock to the system, and extreme climate events may provide that shock.

Collective destiny

It may be that the only way to get broad agreement on climate change action is for politicians and advocates to emphasize local impacts (fires, floods, polar bears, coral) and to avoid describing climate change in global terms other than to announce impending doom (in just eight years, Armageddon). However, some enunciation of the deeper implications might broaden the support for climate-driven policy. In both space and time, humanity has crossed into the unfamiliar territory of destiny studies (Socolow 2015).

In space, there is something anachronistic about national rivalries, when the threats from climate change are unrelated to the adversary's hostility. Is it inevitable that the United States and China will persuade themselves that the other is an implacable enemy and that over the next 25 years they will then devote immense resources to this rivalry? Or, instead, can the message of climate change have a sobering effect? Can we see in climate change the overriding message that humanity has a collective destiny that transcends all borders?

As for time, climate change is clearly a multi-generational project. As such, it forces attention on a still larger project with which humanity is engaged. Ahead of any discussion of how to achieve sustainability, we can hope to find broad agreement on why we value the continuity of the human enterprise in the first place. Why do we need to stick around?

One compelling answer is that no other creatures in the entire universe may have the capacity to investigate and appreciate their own existence, and this very possibility imposes obligations upon us. Perhaps we will learn some day that there are discerning creatures elsewhere, but for now, we must assume that there aren't any. Accordingly, not only must we survive but we must thrive sufficiently to assure the perpetuation of a scientific enterprise that is revealing the story of our existence. We are unwrapping a package and progressively revealing its contents. We are making the world we inhabit more comprehensible: finding gravity waves, sorting out the history of our planet, imaging the brain. Our perhaps unique global project must not be brought to an end.

I worry that, in these cynical times, such an argument will be viewed as a self-serving plea for more resources for science. But it is just one of many forceful arguments for human continuity. We also generate art and music, sophisticated social structures that sort out right from wrong, and a caring for one another that transcends the immediate family. We just forget, sometimes, to find joy in how extraordinary we are.

Three wishes

What world do I hope for in 2045? I have allowed myself just three wishes:

(1) May the planet be at least as hospitable to human beings as it is today.
(2) May there be a praiseworthy record of right-left depolarization in the field of climate change.
(3) May humanity come to appreciate the compelling case for its robust collective future.

The fulfillment of the first wish requires acceptance that human activity is circumscribed by planetary limitations. The second wish can get a boost from broad agreement that "solutions" to climate change need to be pursued with sensitivity to competing worldviews. And the third wish is more likely to come true, the more that humankind appreciates the miracle of its self-awareness.

Habitability, mutual understanding, and collective destiny are the domains of my three wishes. That is, I hope for a post-consumerist, post-tribal world, universally cherishing its future. Perhaps, we will need a few quarter-centuries more.

Disclosure statement

No potential conflict of interest was reported by the author.

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Robert H. Socolow is professor emeritus in the Department of Mechanical and Aerospace Engineering at Princeton University. From 2000 to 2019, he and Steve Pacala were the co-principal investigators of Princeton's Carbon Mitigation Initiative, a 25-year (2001–2025) project supported by BP. His best-known paper, with Pacala, was in *Science* (2004): "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." Socolow is a member of the American Academy of Arts and Sciences, an associate of the National Research Council of the National Academies, a fellow of the American Physical Society, and a fellow of the American Association for the Advancement of Science. His awards include the 2009 Frank Kreith Energy Award from the American Society of Mechanical Engineers and the 2005 Axelson Johnson Commemorative Lecture award from the Royal Academy of Engineering Sciences of Sweden (IVA). In 2003 he received the Leo Szilard Lectureship Award from the American Physical Society. He is a member of the *Bulletin's* Science and Security Board.

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