Witnessing for the Middle to Depolarize the Climate Change Conversation

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Witnessing for the middle seeks to depolarize contentious public issues and to create effective coalitions. It reveals neglected facets of a problem, clarifies the stakes, reduces hype, and facilitates the engagement of people largely on the sidelines. Regarding climate change, many forms of middle-building are under way, notably including the scenario-making that reveals alternative pathways to some specific goal. This essay explores two additional vital middle-building conversations, both focused on the goals themselves. One conversation addresses how to learn faster about how our planet can harm us. The other conversation focuses on the various ways that we can harm ourselves while pursuing nominal solutions to climate change. The two themes are complementary. The more plausible the risks of dangerous climate change, the stronger the case for risky solutions.

The title of this *Dædalus* issue is "Witnessing Climate Change." I presume "witnessing" in this instance to be the secular form of a religious concept, requiring forceful speaking or writing that promotes action on behalf of some societally significant issue.

Usually, I think, people would call someone a witnessing professional only if he or she is taking what is regarded at the time as a radical position and is accepting personal risks. Jim Hansen alerting the U.S. Congress to global warming in his 1988 testimony is an apt example of a witnessing scientist. So, too, is Linus Pauling leading the campaign in the early 1960s to stop atmospheric testing of nuclear weapons because of the inevitable negative consequences of radioactive fallout. And Sherry Rowland and Mario Molina in the mid-1970s pressing the case for banning production of chlorofluorocarbons, a popular class of specialty chemicals then widely perceived to be benign, that they realized would destroy stratospheric ozone.

In all three cases, these spectacular interventions required stepping into a void. But what if the subject at hand has already been extensively debated and the conversation has become highly polarized? In such situations, there is value in a different kind of witnessing, "witnessing for the middle." It is witnessing, because it is provocative and disruptive, and its intent is to drive social change. But

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it does not require advocating what at the time are considered extreme positions. Instead, witnessing for the middle searches for new ground: fresh conversations where neglected facets of the problem can be revealed. This middle-building is not an end in itself, but a lubricant. Its objective is to facilitate involvement on the part of people largely on the sidelines, so as to produce a more widely shared, fuller understanding of a problem and, thereby, to diminish polarization. Middle-building can become self-reinforcing.

One goal of this essay is to expand the conceptualization of witnessing so that "witnessing for the middle" is included.

In the case of climate change, two packages of ideas are in contention. Greatly oversimplifying, in one package, the goal is to stave off imminent disaster, and the move away from fossil fuels cannot be too fast; fortunately, there are specific attractive solutions at hand, notably solar power, especially in its distributed rather than its centralized form. Moreover, success may well bring a desirable shift away from consumerist values toward what used to be called "voluntary simplicity." In the other package, dangerous climate change is distant, even inconceivable, so there is no urgency whatsoever; economic growth based on coal, oil, and gas is tried and true; alternatives can prosper only with excessive government intervention; and if a move away from fossil fuels must, after all, prove necessary, centralized energy solutions – especially nuclear power – are the preferred technologies. Amory Lovins, a leading energy analyst for the past half-century, labeled this polarity the "soft" versus the "hard" path in his classic 1976 essay in *Foreign Affairs*,[1] and the polarity is still very much with us.

Important middle-building efforts to reduce this polarization have been in place for decades. One major effort, not the subject of this essay, promotes the visualization of alternative "scenarios" (pathways to the future) that mitigate climate change to some specified extent. In these scenarios, strategies evocative of both the hard and soft paths gain and lose market share as their costs evolve, decade by decade, perhaps out to 2050 or 2100, often in the presumed presence of a policy that imposes a rising price on greenhouse gas emissions. Technologies of energy supply and use are always modeled, but often nowadays so is the food system, as well as technologies that deliberately remove carbon dioxide from the atmosphere. A scenario can apply to a corporation, a city, a country, or the world. The result is what scientists call an "existence proof," the discovery of what would need to be done. Scenarios have brought climate change to many new audiences.

My interest in this essay is to explore two other middle-building exercises, less appreciated but crucial for finding our way forward. They illuminate not what is required to reach some goal but the merits of the goals themselves. How can we decide whether a goal is too strict or too lax? To answer this question requires understanding two kinds of risks with opposite implications: the risk that the earth is extremely sensitive to what we do day-to-day (the higher this risk, the more stringent the targets we should strive for) and the risk associated with our solutions going wrong (the higher *this* risk, the stronger the argument for more modest objectives). Together, the two complementary themes capture the reality that climate change above all requires risk management, including hedging against both kinds of risks.

The first of these conversations addresses the urgent need for climate science to become more ambitious. (I mean "climate science" to encompass all fields that bear on the physical and biological features of the planet relevant at the global scale, including the many implications of human activity; increasingly, this domain is also called "Earth systems science.") I have two kinds of ambition in mind: 1) giving priority to the hard question of how quickly very bad outcomes could show up (like fast sea level rise) and 2) recruiting large numbers of researchers now working on fundamental problems in many relevant areas (chemists, physicists, computer scientists, experts in control theory, to give four examples) but so far showing little interest in climate change.

The other conversation is about the dark side of "solutions" to climate change and the need for vigilance. For precision, the conversation needs a time frame, which in this essay is the next ten to twenty years. In that period, several strategies to combat climate change (notably, nuclear power, land managed for carbon, and geoengineering) could create havoc on a par with climate change itself, if implemented heedlessly.

A modern version of the Hippocratic Oath provides a metaphor for the two-sided reasoning this essay seeks to encourage: "I will apply, for the benefit of the sick, all measures that are required, avoiding those twin traps of overtreatment and therapeutic nihilism."[2] In medical treatment, many of us are acquainted with such fateful choices: A drug with promise has strong side effects. Administer it, or opt for another drug less likely to succeed but with milder side effects?

There is some irony in middle-building exercises that are explorations of extremes. Yet the argument is quite general: people will agree on the importance of anticipating the worst that can happen. Such concerns bring people together in times of war.

The middle-building bearing on climate change that I am recommending must not be construed as an excuse for delay. Addressing climate change aggressively is an urgent matter. "It is essential to know more" does not imply "wait for more information." Rather, the question I am posing is: what else could we be doing that is likely to be productive?

By emphasizing the importance of exercises that invite heterogeneous participation, I am countering the view that building a "movement" is a sufficient strategy for limiting climate change. A movement intentionally creates polarization, because, as Gus Speth, one of my generation's most effective environmental leaders, explained to me, it "needs victims and villains." It is deeply judgmental. A climate change movement would be self-defeating if it were to stifle a critical and more embracing public discourse.

We need both middle-building and movement-building. They complement each other. As many of us learned from protesting during the Vietnam War, only when the near-left finally joined the far-left could the war be stopped. Witnessing on behalf of instant dramatic action on climate change has been productive: it has primed the pump. To bring about forceful and coherent activity going forward, however, I believe that witnessing for the middle will be essential.

Where am I coming from? I have engaged with climate science and climate solutions in numerous ways over the past half-century. In 1971, in my early thirties, I left a faculty job in theoretical physics (quarks) at Yale for a new faculty position in Princeton University's School of Engineering and Applied Science. I had become fascinated with the idea, then completely new to me, that we humans are changing our planet in immensely disruptive ways by doing ordinary things. I committed myself to following this idea wherever it led. The job at Princeton, newly minted, came with the expectation that I would invent interdisciplinary research related to energy and the environment. I have focused on solutions to climate change, including energy efficiency, nuclear power, wind and solar power, and low-carbon energy from fossil fuels. I have ranged widely across the university, problem-driven rather than discipline-driven. For the past two decades, my office and academic home have been in the Princeton Environmental Institute, a university-wide multidisciplinary unit dominated by climate science.

I trace my need to witness to my secular and religious schooling: a progressive high school run by the Ethical Culture Society and an iconoclastic Hebrew School run by the Jewish Reconstructionist Society, both committed to fostering nonconformity and the student's social conscience. Moreover, Reconstructionist Judaism, which affirms a rebellious blend of modernity and tradition, taught me to cultivate the middle. My fascination with global issues was fostered by a yearlong travel fellowship spent in Asian and African countries transitioning to independence. My skepticism when I confront advocacy on behalf of some solution to climate change derives from being a lawyer's son who heard repeatedly: "My job is to help my client think about what he does not want to think about. If something can go wrong, it will go wrong." As for my specific conviction that fresh conversation can transform knotty problems, please allow me to tell four stories (one paragraph each).

My initiation into environmental problem-solving in 1969 centered on the conflict between developers seeking to build a major international airport halfway across the Florida peninsula west of Miami and environmentalists determined to protect the flow of water to the Everglades at the peninsula's southern end. My contribution (together with my then Yale physics colleague, John Harte) was to highlight the interests of other land developers: those who were about to create cities on the peninsula's west coast that would require substantial inland standing water to protect their water supplies. The jetport would jeopardize such water reserves. When they and other Gulf Coast interests weighed in, President Nixon decided against the airport and, in 1974, the 720,000-acre Big Cypress National Preserve was established instead.[3] In the language of this essay, a middle-building exercise had broadened the discussion and had enabled more of those with a stake in South Florida to imagine alternative futures.

My first multidisciplinary project at Princeton in the 1970s was one of the earliest field studies of energy use in mainstream residential housing.[4] We sought to understand the roles of design, construction, and occupant behavior by instrumenting actual homes. We deliberately chose average buildings – in this case, recently built row houses for middle-income families – which led to our group being attacked from two directions. The architecture community was dismayed that we were not studying the distinctive buildings that architects design, buildings that have enduring significance. Advocates for social justice told us it was close to immoral not to focus on the housing of the poor in inner cities, where the needs were so compelling. I answered that we hoped to contribute toward reducing the total energy use in all buildings, and ordinary buildings dominate that total. Indeed, our project stimulated a fresh conversation about energy use in buildings that spawned a major national effort to develop higher performance windows, lighting, and appliances in every kind of building. It also prodded electric and natural gas utilities to include feedback to the customer (graphical comparisons of present and past consumption, for example) in their monthly bills, which has raised awareness.

Starting in 1983, with several others, I organized a decade-long collaborative project with Soviet (and then Russian) counterparts focused on efficient energy use in buildings and industry.[5] The impetus for that project was President Reagan's speech calling the Soviet Union an "evil empire" and communism "the focus of evil in the modern world." In that speech, I foresaw the beginnings of a process that would demonize Russians and gradually reduce our inhibitions against obliterating them. I recalled jumping off small rocks in Central Park in Manhattan at age six or so, with my two index fingers pulling my eyelids outward, shouting "banzai," as we American boys were being carefully taught to demonize the Japanese. Scientists on both sides, similarly frightened by the invocation of "evil," developed fresh conversations, of which this was just one example. Our project led to some new energy-efficiency initiatives in the Soviet Union. In the United States, we needed to defend ourselves against charges of helping the enemy.

From 2000 until 2019, I codirected (with Steve Pacala, an ecologist) a large university-wide research program sponsored by BP, a major oil company. Some environmental activists are baffled that I enjoyed working with BP and continued the relationship in spite of the 2010 Deep Horizon accident and oil spill. The payoff for me has been the opportunity to influence BP's executives. My colleagues and I provide a safe place for them to ask basic questions, and we provide a counter-narrative that refutes what they hear in industry settings. Their visits to Princeton almost always include a tour of the walk-in freezer with ice cores from Antarctica that chronicle, in their trapped bubbles of old air, the oscillations of the atmospheric carbon dioxide concentration through the ice ages. We inoculate these business leaders against their own credulity, and they begin to modify their company.

These four middle-building experiences lead me to believe that the two risk-focused exercises I briefly introduced earlier will be similarly effective in generating fresh conversations that lead to social change. I elaborate first on dangerous feedbacks in the earth system and then on misdirected climate solutions.

If the world addresses climate change forcefully, nations will spend trillions of dollars over the next few decades to overhaul the world's current energy system and to repurpose the current uses of land. We are preparing to swap an energy system that currently is 80 percent coal, oil, and natural gas, in favor of one in which these fuels become minor players. We are considering dedicating current pastures and farmland to energy crops and harvesting solar energy and wind at nearly continental scale. We are creating plans to relocate coastal communities. We are taking the first steps toward placing the control of climate change into our own hands ("geoengineering" the planet).

It is truly remarkable that at a time when such monumental transformations could lie in our immediate future, there is hardly any strong advocacy for deepening our understanding of how we are affecting our planet: not even for additional satellites, more probes of the deep ocean and glaciers, more sensors in the forests. Normally, when a corporation takes on a new line of business, it develops a research capability to buttress its new investments. And when a country develops new allies or enemies, it spends heavily on understanding their cultures and languages. But for climate change, the urgency of substantially improving the knowledge base is scarcely part of public discourse today. The complacency about climate science is anomalous.

To be sure, climate science already captures our planet's behavior well enough to motivate decisive action. Nonetheless, climate science at present can only partially delineate what is in store for us. Severe climate change could show up slowly or quickly. This is the clear message of the reports of the Intergovernmental Panel on Climate Change (IPCC), which summarize the state of the science roughly every six years. The IPCC repeatedly warns us that far less is known than would be desirable about the amount of climate change the world will be contending with a decade from now, and half a century from now. Even when human contributions are fully specified, the worst and best plausible outcomes for the future of humanity consistent with current science are very different.

When the stakes are so high, why is the climate science enterprise so nearly invisible to the public, and why does it have so few champions? A partial explanation lies in the stances of those at both poles of a basic argument about climate change. Many climate activists insist that "the science is settled." They fear that calling attention to what still could be learned will undermine the case that we already know enough to act. They may also be wary of politicians espousing "more research" as a way to postpone an effective policy response. At the other pole, those whose goal is to forestall action regularly argue that climate science is so politicized that it provides no guide at all; for them to urge a more ambitious program, they would need to concede that the climate science enterprise is redeemable.

A broadly supported climate science enterprise would prioritize the need to understand how soon very large negative impacts could afflict humanity. Much depends on the many feedbacks within the climate system, each of which can either amplify climate change (a positive feedback) or suppress it (a negative feedback). A positive feedback occurs when increases in atmospheric carbon dioxide warm the Arctic, leading the permafrost to disgorge more carbon dioxide that warms the Arctic further. Another positive feedback occurs if, on a warming planet, some low clouds start to fade away, and the extra sunlight reaching the earth's surface removes more clouds. A negative feedback occurs when extra carbon dioxide in the atmosphere stimulates the growth of forests, which in order to grow must take carbon dioxide from the atmosphere. The future strengths of these and similar feedbacks dominate our uncertainty about the future climate.

A multifaceted climate science effort might "retire" some currently salient risks. We may learn that a particular positive feedback is nearly certain to remain small, but that another may well become debilitating. To be sure, deciding how much to weight the planet's worst changes requires a prior effort to sort out the meanings of "worst." This can be accomplished only by blending in the insights of the social sciences and the humanities. Many severe changes to the planet in physical terms can be made less costly by investments in resilience, communication, and governance. There is also a need to take into account who will suffer most. Middle-building to anticipate and prepare for extreme climate change requires all hands on deck.

At its most extreme, a positive feedback becomes a tipping point that produces radical changes in the entire climate system. (The unbearable noise produced by a microphone and a speaker when they get too close to each other is the result of a feedback that has crossed a tipping point.) My colleague, Steve Pacala, calls the positive feedbacks of the climate system "monsters behind the door." It seems that no monsters are yet among us: climate feedbacks are operating nearly as they have operated in the past and are not changing quickly. But what if one or more monsters escape? The late Martin Weitzman posed this question quantitatively within the context of cost-benefit analysis. He pointed out that although his fellow economists had long assumed that the average responses of our planet deserve nearly all the attention, plausible nasty behaviors of our planet could actually be paramount reasons for action.[6]

Imagine a counterfactual in which the global climate resembles the current climate, with overall warming, shrinking Arctic ice, and the other features that now alarm us, but climate science hardly exists. The atmospheric concentration of carbon dioxide has risen to today's level, but scientists have not discerned its key role. We are not in the counterfactual state because of some fortunate decisions in the history of science. In 1958, geochemist Charles David Keeling began measuring the atmospheric carbon dioxide concentration high up on the Mauna Loa volcano on the island of Hawaii. At that time, many scientists thought this was not a sensible idea, expecting the concentration to be patchy, reflecting variable wind patterns that would sometimes bring distant industrial emissions into the measuring instruments and sometimes not. Keeling and those who supported him guessed right, and the results were reliable. At about the same time, a few far-seeing scientists created new institutional capabilities to coordinate simultaneous studies of Earth from many places. The International Geophysical Year of 1957 – 1958 produced Antarctic ice cores that revealed the level of carbon dioxide in the atmosphere through eight ice ages. Keeling's Mauna Loa record and the Antarctic ice cores are cornerstones of the climate science edifice. Each is a great story, worthy of inclusion in new curricula at every education level, from elementary school through college.

In short, we are deeply in the debt of the climate scientists, a few thousand people. Without them, we would be flying blind.

Why do I feel so driven to call for a more ambitious climate science effort, as a primary response to the high societal risks from climate change? During my short period in theoretical physics, culminating in five years on the Yale Physics faculty, I saw the norms of science at their best: openness and welcoming, contention and resolution (the Big Bang versus continuous creation, for example), error correction, the winnowing of the central from minor issues by the artful back-of-the-envelope calculation, and deliberate strategies (like the double-blind experiment) that inhibit the self-confirmation bias that leads people to find what they want to find. Fundamentally, I believe that science is a privileged way of knowing, that science provides humanity's most reliable searchlight as we navigate troubled waters.

Accordingly, I find it portentous that participation in climate science is on the minds of so few scientists in neighboring disciplines. I can point to some wonderful exceptions, but I wish that a greater number of senior investigators in neighboring fields were redirecting their research and urging their students to join them.

I conjecture that this distancing by scientists in neighboring disciplines can be attributed in part to their disinclination to give the benefit of the doubt to the findings of climate science that they read about in the popular press. I have heard such skepticism in countless conversations about climate science over the years with scientists and engineers in other fields, especially in physics. Much of this distancing, as best I can determine, is a response to the politicized messaging around climate science. Great distress spread through the American Physical Society (the professional society of American physicists), for instance, when one of the Society's public statements said that evidence for human-induced climate change was "incontrovertible." Many members were appalled. After all, no finding in science can be beyond controversy. The history of physics is replete with revisions of previous orthodoxies. The Society decided to revisit the statement, and "incontrovertible" was set aside.

A specific source of the scientists' misplaced skepticism is the widely promulgated claim that "97 percent of climate scientists" believe that currently observed climate change is at least partially human-induced.[7] The statement is probably an underestimate. But if the goal is to persuade a scientist that some specific research community is conducting its work according to the norms of science, assertions that 97 percent of scientists in that community believe X (no matter what X is) are counterproductive. Science isn't about believing, and it isn't about voting; every good scientist leaves room for doubt. When a scientist in another field hears "97 percent," she worries whether this is a field seeking consensus rather than searching for disruptive insights; she worries, even, that there may be coercion. From my perch, I find that the norms of science are scrupulously practiced and well defended by climate scientists. Still, no other area of science is shackled by anything resembling 97 percent, as far as I know.

It is sobering to learn, however, that the "97 percent" argument has been singularly effective in persuading lay audiences that climate change science is well-grounded science, not up for grabs. It directly addresses the counterargument that there is no consensus at all among climate scientists, which has been the weapon of choice for interest groups seeking to undermine initiatives responsive to climate change. It is not surprising, therefore, that 97 percent is so prevalent. Evidently, the 97 percent argument is being heard entirely differently by public and professional audiences.

The second middle-building exercise I am advocating in this essay addresses the solutions to climate change. The two-sided reasoning in the Hippocratic Oath is with us again. The burden of proof is on those who would take an option off the list. However, there must be room not only to say *yes* to a solution, but also to say *no*. A useful word is "conditionality": the constraints policy-makers should impose when they facilitate the deployment of any solution. Another word used for these constraints is "guardrails."

In evaluating solutions, engaged citizens like you and me need to be wary, but also to keep an open mind. Within a decade or two, there may be some exciting new technologies, and some countries may have adopted stringent emission-reduction policies (a very high carbon price or its equivalent) that transform energy and land-use competitions. On the other hand, some solution may have been introduced at too fast a pace, in the sense that it has induced a level of resistance that requires starting again.

The world has a portfolio of solutions, as Steve Pacala and I illustrated with an ecumenical analysis in 2004.[8] The conversation about solutions is actually many parallel conversations, each focused on a single important pathway. Pacala and I called these low-carbon options "stabilization wedges," conveying that they have the potential to grow steadily to reach a climate-significant scale from a small base. Quantitatively, a full wedge is a strategy that reduces the global carbon dioxide emissions rate fifty years from now, relative to what it otherwise would be, by the equivalent of 10 percent of the current emissions rate.

To keep this essay within a reasonable length, I discuss several of the wedges being taken seriously today, but by no means all of them. Not addressed are the many lifestyle choices made by the prosperous in all countries that affect climate, such as diet, travel, and the acquisition of possessions;[9] I do discuss family size. I omit hydropower and geothermal energy, two important electricity supply wedges. I also do not consider hydrogen-related wedges. Suffice it to say that several strategies involving hydrogen (a carbon-free fluid) could become important, because hydrogen can be produced in many ways and can displace fossil fuels in many of their current roles in industry and transportation. Hydrogen competes with electricity and is disadvantaged in that competition because hydrogen requires a new energy infrastructure.

Every wedge offers opportunities for middle-building conversations. Below, for each wedge, I identify such conversations.

Energy efficiency and electrification. Sharp reductions in energy consumption are essential in a climate-responsive world. Fortunately, deep trends in technologies have long pointed toward lower energy use. New materials, new sensors, and new data-processing algorithms (in aggregate, "smart" technologies) are enabling a host of relatively risk-free technological and social innovations that fulfill human needs with minimal involvement of the beneficiary. To cite a single insufficiently celebrated example, the highly energy-efficient light-emitting diode (LED) is displacing most other lighting technology.

When it comes to reducing carbon dioxide emissions, energy efficiency is joined at the hip with the electrification of the economy. The reason is that the use of oil and gas as fuels cannot be eliminated with energy efficiency alone. A two-step shuffle holds center stage: substitute electricity for the oil or gas, while in the same time period greatly reducing the carbon dioxide emissions associated with producing the electricity. Shifting from the gasoline-powered to the electric car is probably the best example of a wedge based on this two-step shuffle: the battery-powered vehicle is poised to transform transportation, but the carbon dioxide emissions from driving won't fall much, if at all, if the electricity charging the car's battery is produced from coal.

In the way, nonetheless, are societal inertia, misaligned economic incentives, and mistrust of innovation. An apt example is the challenge of overhauling the ways that buildings are designed and constructed. The unrealized opportunities are transnational: the many complexes of apartment buildings currently under construction in the expanding cities of the industrializing countries are locking in much unnecessary energy consumption by copying the suboptimal practices and policies that shaped comparable projects built decades ago in now industrialized countries: notably, the "first-cost bias" that ignores all costs incurred after occupancy. The obstacles are similar in transportation, heavy industry, agriculture, and other economic sectors. Middle-building conversation would focus on ways to accelerate the realization of energy-efficiency wedges, sector by sector.

A broad conversation would also encourage a search for ways to assure a balance between promoting low-carbon options and protecting individual liberty. The recent opposition to the elimination of most incandescent light bulbs from U.S. markets provided a taste of arguments that lie ahead, many of which will be more difficult to dismiss. Indeed, a similar pushback may emerge over policies designed to end all cooking with gas in favor of cooking with electricity. I worry about zealotry on the part of the proponents of energy efficiency. An apt quote is from John Maynard Keynes: "Madmen in authority who hear voices in the air are distilling their frenzy from an academic scribbler of a few years back." Any campaign to restrict the use of air conditioning or airplane travel, for example, will require careful listening, not frenzy.

Fewer people. The demographic transition (falling birthrates) has substantially reduced climate change over the past fifty years, and is expected to continue to do so. Parents exhibit a nearly universal preference for fewer children as they become wealthier, to such an extent that the populations in an increasing number of countries are already falling, and the global population may well head downward at midcentury. All else being equal, a smaller population brings with it the consumption of fewer resources, less crowding, and more room in the atmosphere for the emissions of future generations. However, a falling population can be unnerving and lead a government to bribe or coerce parents to have more children than they wish. Granted, the demographic transition creates a population that grows steadily older on average, a challenge already with us. And surely, populations can fall too quickly. One task for the middle-builders is to examine transitions that align falling populations with social stability. For example, how might governments incentivize more of the healthy elderly to remain contributors to the economy?

Solar and wind power. The dramatic reductions in the costs of solar and wind power over the past two decades have created an expectation that they will be the workhorses of the future global energy system. Both are growing rapidly. Remarkably, the owner of a single solar panel providing refrigeration and cell-phone charging at her remote village hut is benefiting from the same feats of semiconductor science and manufacturing as the suburban household drawing power from a rooftop array or a million-panel facility in a distant desert. And platforms for wind turbines are marching offshore into steadily deeper water, much as platforms for oil and gas drilling did earlier.

Obstacles to expansion are appearing, however, as solar and wind power gain market share. The best solar sites aside from deserts are pristine south-facing hillsides (in the Northern Hemisphere), the best onshore wind sites are ridges, and the best offshore wind sites are within view of coastal communities – assuring resistance to intrusions on landscapes and seascapes and counter-pressures to preserve the wilderness experience. Similar siting conflicts may thwart the march of high-voltage power lines across hundreds of miles of countryside to connect these remote locations to major population centers (replacing the transport of the chemical energy in coal, oil, and natural gas by rail and ship and pipeline). Greater compensation for affected communities will reduce hostility in some situations. It is highly probable, however, that location-related concerns will diminish the competitiveness of wind and solar power, as they do other energy sources. Middle-building conversations would get out ahead of these place-based controversies.

Wind and solar power, unlike most other energy sources, are not at our beck and call. Shortfalls measured in seconds and hours can be accommodated with the help of batteries. But shortfalls measured in week-long stretches of wind lulls or cloudiness (or both) will require responses that come, at least partially, from the users of electricity. Especially interesting and fraught, consumers may be asked to forego the luxury of instant gratification of their demand for electricity no matter what the cloudiness and windiness outdoors. A more supple energy system may evolve that promotes behavioral accommodation (washing clothes only on sunny days and drying them outdoors, for example, as was the norm in my childhood). Although technological strategies to store electricity or heat for long periods of time are available in many locations, the ultimate contributions of wind and solar electricity will be much larger if consumers tolerate – even welcome – weather-driven modifications of their behavior. Adapting to intermittency is a good topic for middle-building.

Capture of carbon dioxide from fossil fuel power plants and other industrial facilities. An important low-carbon strategy is to keep out of the atmosphere the carbon dioxide produced during the combustion of coal, or oil, or natural gas at (eventually) every centralized facility where these fuels are burned.[10] In this process, the carbon dioxide is extracted from the exhaust-gas mixture heading for the chimney, before it reaches the air outside. Then, the carbon dioxide is piped into a geological formation deep underground where it can be stored at least for centuries. (An alternative to burying the carbon dioxide is to make a durable material out of it.) To contribute a wedge, a new below-ground industry would need to become comparable in scale to the current oil and gas industries. Emergent problems include the risk of triggering an earthquake during carbon dioxide injection, which seems already to be slowing deployment in Japan. There is also the potential, in poorly characterized storage sites, for upward leakage of carbon dioxide into ground water. These problems are not insurmountable.

The political implications of so-called "carbon dioxide capture, storage, and use" are intriguing. This wedge enables the fossil fuel industries to contribute solutions to climate change and enlarges the potential pro-mitigation coalition. It makes the winding down of the fossil fuel era a less precarious undertaking by creating new assignments, still consistent with strong climate goals, for the current entrenched labor force producing and distributing gas, oil, and coal, and it allows a repurposing of much of the existing infrastructure.

This wedge has few fans, however, and not because it has proven to be infeasible. Indeed, a modest carbon dioxide pipeline infrastructure already exists, and promising variants of the key technologies are arriving. Yet the coal, oil, and natural gas industries provide lackluster support, unpersuaded that governments will sustain the necessary incentives. At the same time, many activist environmental organizations oppose the strategy. Some argue that, on the basis of current practices in the fossil fuel industries, one should expect regulatory capture and lack of transparency. Others go further, arguably motivated as much by ending the fossil fuel era as by slowing down climate change. They rightly see this wedge providing an escape route for fossil fuel in a "decarbonized" world, and they simply do not want this option to succeed. Sorting out the merits and demerits of carbon dioxide capture, storage, and use is yet another promising middle-building exercise.

Direct capture of carbon dioxide from the air. Carbon dioxide can be removed directly from the air with chemicals, just as it can be removed from industrial effluent (the low-carbon wedge just discussed). However, only one in twenty-five hundred molecules in the air is carbon dioxide, as compared, for example, with one in about twenty-five molecules in the exhaust gas at a natural gas power plant. As a result, the capture technologies are very different, and far more hardware is required to capture the same amount of carbon dioxide from the air than from flue gas. But the steps subsequent to capture are exactly the same: the carbon dioxide must then be either stored or used. This low-carbon option is called "direct air capture."

Direct air capture is a "negative-carbon" strategy, meaning that it reduces the amount of carbon dioxide in the atmosphere. Several decades from now, direct air capture and other negative-carbon strategies may be deployed at such a large scale that they drive the carbon dioxide concentration of the atmosphere downward. For the next few decades, however, this wedge will be hampered by the large amounts of energy required to drive its associated mechanical and thermal equipment. In many locations today, the quantity of carbon dioxide emitted into the atmosphere in conjunction with running an air-capture facility would be comparable to the quantity of carbon dioxide that the facility extracts. The argument for building direct air capture projects now, while the world's energy system is only slightly decarbonized, is to gain experience and buy down the costs.

Negative-carbon strategies offer ways to cancel the most recalcitrant emissions, like those from airplane jet fuel. Corporations are already offering products with "net-zero" carbon dioxide emissions by tying a product to a negative-carbon project and asserting that the emissions associated with making and using the product are "offset" by atmospheric carbon dioxide removal. Large companies and start-ups are already teaming up to conduct the first negative-carbon demonstrations. Extensive use of third-party verification and the resolution of a host of nettlesome accounting issues will be required for carbon offset markets to flourish at a climate-significant scale. Middle-building can create the consensus required to formulate the rules of the road.

In my opinion, neither energy efficiency, nor solar power, nor wind power, nor fossil energy use accompanied by carbon dioxide capture, nor direct removal of carbon dioxide from the atmosphere has a downside as ominous as three further climate-driven energy strategies that conclude this section: nuclear power, biocarbon, and solar geoengineering.

Nuclear power. Fifty years ago, I believed that the case for deploying nuclear energy instead of fossil fuels would prove to be so compelling that it would lead to a broad disavowal of nuclear weapons by the world's nations, a durable taboo on their use, and steady progress toward nuclear disarmament. Rather, the opposite has happened. Nuclear weapons are desired by more countries today than fifty years ago and even a decade ago. The global nuclear power wedge is perilous because national nuclear power programs provide cover for nuclear weapons development and make nuclear war more likely.

Conditionality in this instance means forestalling any major expansion of global nuclear power until such time as there are global institutions that manage the nuclear fuel cycle so well that there is no ancillary promotion of nuclear weapons. This probably necessitates the international ownership of all uranium enrichment and nuclear fuel reprocessing wherever either is pursued, as advocated by Mohamed ElBaradei when he was director general of the United Nations International Atomic Energy Agency.[11] It also requires serious progress in delegitimizing nuclear weapons, and the retention in each successive generation of the understanding of just how horrible nuclear war is.

In an essay in the Fall 2009 issue of *Dædalus* "On the Global Nuclear Future," my nuclear scientist colleague Alex Glaser and I struggled with the merits of global nuclear power as a route to reduced climate change. After conceding that "the upper limits of climate change are terrifying, amounting to a loss of control of the climate system as positive feedbacks of various kinds set in," we nonetheless "judge the hazard of aggressively pursuing a global expansion of nuclear power today to be worse."[12] Alex and I still agree with what we wrote then.

Middle-building exercises would address not only connections to nuclear weapons, but also the escape of radioactivity from nuclear facilities. The latter could result either from an accident in peacetime, or from a terrorist attack, or from being targeted in a war. From the 1986 accident at Chernobyl in the then Soviet Union (documented brilliantly in the recent book *Midnight in Chernobyl*) and the 2011 accident in Fukushima, Japan, one may infer that the regulatory process is so prone to capture by the nuclear industry that major releases of radioactivity cannot be excluded.[13] Moreover, a nuclear power plant accident has a distinctive feature, evident in the responses to those two disasters, which is contagion: an accident at any nuclear plant creates strong pressure to shut down every other nuclear plant.

Biocarbon. There is several times as much carbon in the earth's forests and grasslands and soils ("biocarbon") as in the atmosphere (where nearly all of it is in carbon dioxide). In the course of a year, plants use photosynthesis to take carbon from the atmosphere in the growing season and return carbon to the atmosphere as they decay; in most places these two flows approximately balance out. Currently, there is considerable interest in biological wedges that shift that balance slightly, moving some atmospheric carbon into vegetation.

Planting a new forest is one way to accomplish the transfer. What needs to be taken into account so that this specific undertaking does not go awry? Consider, for example, that you are a forester working in a country that is heavily subsidizing the removal of carbon dioxide from the atmosphere. Your boss buys an extensive land parcel and puts you in charge of planting a new forest there; she tells you that storing as much carbon as possible on the land is your only objective. What do you do? Establish a monocrop? Pour on fertilizer? Be inventive.

Now, change roles. You are a policy-maker in that same world, designing a market that is rewarding carbon removal, and you are motivated by broad social and environmental goals. What conditionalities do you insert into the carbon market in the interest of eliciting the land use and forestry you welcome and deterring outcomes you decry? You could prohibit using land now in agriculture, so as not to restrict the food supply. You could require the biodiversity value of the land to be taken into account, as well as the forest's effect on local water, and whether there are forest dwellers nearby whose lives will be disrupted. The subsidy could be only for "net carbon," where the carbon dioxide emissions associated with chainsaws and trucks are subtracted from the carbon stored. If the forest is to be actively managed for timber, you could credit not only the carbon in the forest but also the carbon from that forest stored in the beams and trusses of buildings that may stay in place for a hundred years.

This vignette gives a glimpse of the complexity of biocarbon solutions. The story is similar if ethanol for vehicle fuel is produced from corn or sugarcane, displacing gasoline. Or if crop and forest "wastes" are processed at bio-refineries to produce climate-friendly chemicals.

A particularly interesting variant, biological energy with carbon dioxide capture and storage, is another negative-carbon strategy, like direct air capture. Photosynthesis transfers carbon from the air into a living plant, which is then harvested and burned to generate electricity. If chemicals capture most of the carbon dioxide in the exhaust of this biomass-fueled power plant, and this carbon dioxide is then stored for the long term, the net result is to reduce the amount of carbon dioxide in the atmosphere.

At the global level, mitigating climate change primarily through manipulations of the biosphere requires the use of a significant fraction of the earth's land. The underlying reason is that photosynthesis is an extremely inefficient process for converting sunlight into energy. Consequences for global food production and biodiversity can be devastating without careful planning. In contrast to some of the other options just discussed, extensive conversations about opportunities and threats related to most biocarbon wedges are already underway.

Solar geoengineering. If we human beings can now modify our planet inadvertently by pursuing everyday activities, it should not be surprising that we also now have the capability to manipulate the planet deliberately with targeted measures: to "geoengineer." In particular, we have the capability to reduce incoming sunlight to compensate, at least partially, for our current warming of the planet. One scheme increases the reflection of incoming sunlight by modifying the upper atmosphere (the stratosphere). A closely related concept makes the tops of clouds brighter.

The immediate decisions today are about small-scale field research. Many advocate prohibition. They doubt that human beings will ever use tools wisely that can manipulate the whole planet; in particular, they see no plausible route to global governance. Some of these critics see a slippery slope where small-scale experiments with no lasting impact lead to some much larger experiment that creates the very disaster it was meant only to learn about. They are opposed by others who, in support of field experiments, insist on the need to be prepared; the earth could soon reveal itself to be at the upper end of sensitivity to human perturbations, and it is therefore incumbent on the research community to move promptly to develop the means to counter the adverse changes. Geoengineering might be able to retard sea level rise, for example.

Disquieted by how poorly we understand our planet, I see the cart in front of the horse here. The systems that are candidates for manipulation through geoengineering (the stratosphere, clouds, and several others) are the same as the systems requiring deeper understanding to fathom the risks of human-induced climate change in the absence of geoengineering. A prudent research plan would give priority to how our planet works now, and it would treat whatever benefits accrue to geoengineering as subordinate. Inevitably, much of the new knowledge of the earth that will be acquired in the near future will be "dual use," a phrase invoked in the sphere of national defense to describe technology with military and nonmilitary applications. This commonality between arms control and geoengineering alerts us to the need to guard against risk assessments of geoengineering that are bloodless and feature excessive quantification.

I expect that the mission of solar geoengineering will expand beyond planetary-scale cancelation of global warming to include objectives bearing on human comfort and convenience at much smaller scale, and I fear the consequences for other species. How will they fare if we humans use solar geoengineering to remove hurricanes and heat waves and droughts? Countless species occupy ecological niches that depend upon climate extremes: the plant that flowers only during hot spells or that thrives in a flash flood, for example. Many of these niches will disappear, possibly to our long-term detriment, if we are not able to resist making the crooked straight and the rough places plain.

Conversations about geoengineering are likely to be the most contentious of all those I have proposed. Geoengineering engages profound feelings about human destiny. It requires us to ask what level of control of the planet human beings ought ever to have.

The risks of solutions were not considered in the global diplomatic process leading to the Paris Agreement negotiated in 2015, which identifies the world's goals for climate change management. Only the risks of climate damage were motivating. Implicitly, the diplomats were expressing their confidence that the science and engineering community is clever enough to get us there safely.

The overarching Paris goal is simple to understand. Referencing the average surface temperature of the planet, it affirms the desirability of constraining future activity so that this temperature never rises even as much as 2 degrees Celsius (3.6 degrees Fahrenheit) above its value in "pre-industrial" times (a period of several centuries ending around 1800, during which this temperature was roughly constant). Simplifying, the Paris goal requires the average surface temperature to stay "well below" – language used in the agreement – 16 degrees Celsius (about 61 degrees Fahrenheit), because the pre-industrial average surface temperature was about 14 degrees Celsius (about 57 degrees Fahrenheit). The temperature rise thus far has taken us about halfway: the average surface temperature has risen close to 1 degree Celsius.

The nearly universal acceptance of the "two-degrees" goal is a triumph of diplomacy. Worldwide, it has spawned countless supportive quantitative commitments and placed palpable pressure on corporations and governments to begin the required rapid transformations of technological infrastructure and land use. The two-degrees goal is a social construct, however, not a scientific finding. Science has not identified any line in the sand, a boundary between safe and unsafe. We do know that climate change gets steadily more dangerous as the earth warms. But as far as anyone knows now, 2 degrees Celsius is not a tipping point. As best I can tell, even the affirmatively risk-driven global climate science program I have advocated is not likely to pin down tipping points, even though it will improve our understanding of the earth's many feedbacks. Our planet is just too complicated.

The world may go past the two-degrees target. In already industrialized countries, the target requires overhauling entrenched institutions and replacing infrastructure long in place. In industrializing countries, the target requires severe departures from historical patterns of development (leapfrogging). The world is not yet prioritizing either of these challenges. Indeed, the industrialization ahead in Asia and Africa is a good candidate for another middle-building exercise. In what proportion, for example, will India build coal power and solar power, and what are the critical determinants of that fateful and imminent choice inside and outside the country? So far, conversations about such urgent questions are rare.

A world unprepared for exceeding the two-degrees target could succumb to panic and defeatism. Panic could lead to an uncritical embrace of dangerous solutions. Defeatism could bring a cessation of effort, even though at no future time will inattention to climate objectives be preferable to continued concerted action. Three degrees of warming is immensely safer than five degrees (Celsius! A Celsius degree is 1.8 Fahrenheit degrees, and five Fahrenheit degrees of average surface warming is immensely safer than nine degrees). We need to prepare a soft landing for "two degrees," in case we turn out to need it.

Is witnessing for the middle an oxymoron? Isn't it just a way of playing safe? Can witnessing for the middle ever move the needle more quickly and less reversibly than witnessing for an extreme? If witnessing for the middle can reconfigure the debates, clarify the stakes, reduce hype, and create effective coalitions, then yes it can. I have provided two examples of activities that can contribute to these objectives, both focused on the risks of worst outcomes: in one case, the risks inherent in our not being able to rule out a very unstable planet, and in the other case, the risks of misapplied solutions. In essence, I am advocating for opening two new conversations.

What conditionalities ought to be placed on middle-building itself? Some will doubtless argue that the all-encompassing global climate crisis is so grave that uncompromising extremism is justified: it is appropriate to present the immediacy of the crisis and the goodness of solutions without qualifications. This position will remind some readers of what Barry Goldwater said in his 1964 presidential nomination acceptance speech at the Republican National Convention: "extremism in the defense of liberty is no vice." What about that sentence was so upsetting at that time? Is it less menacing today? Granted, nuance can diminish the commitment to action. But surely, in dealing with a threat that, however dire, will likely remain ill-defined for a long while, it is essential to build a resilient climate change discourse by telling the story straight.

The story is about the collective destiny of humankind on our planet, which is a quite new concern. Here is how I would tell the story so far, in four paragraphs.

The planet we inhabit is so small that we are able to change it inadvertently with everyday activity. Humanity is only just beginning to scope the dramatic revisions of current practices that must be pursued on a planetary scale over many decades in order to sustain our collective well-being and the well-being of Earth's other species. The implications are particularly severe for the many nations that have most of their industrialization ahead of them; as best we know, the planet cannot stay safe unless they follow novel development paths. Simultaneously, the already industrialized countries will need to overhaul their own infrastructures.

Climate science already provides an ample foundation for prompt action that slows the arrival of climate change. Nonetheless, climate science is incomplete. Climate scientists are gradually clarifying how the planet works, helped by the earth itself, which is gradually revealing its secrets. There is ample justification not only for much more ambitious climate science but also for greater focus within climate science on investigating best and worst outcomes, especially worst outcomes. Global climate change requires sustained risk management, which in turn requires ever bolder climate science.

Workable solutions are either at hand or in view. But every solution that mitigates climate change can be dangerous, if deployed inattentively at large scale. Every solution is a strong drug, with known and unknown side effects. Accordingly, we must resist any framing that contends that, in climate change, humanity faces a single overriding problem and that we must throw caution to the winds to solve it, subordinating all other objectives. No matter what the proposed solution, we must investigate every feature that might lead us to reject it. People intuit that solutions poorly applied could have unappealing consequences for getting and spending and bucket lists, for family size, for equity, for international security, for environmental soundness. Vigilance is the name of the game.

The human predicament is universal. All of us alive today, like it or not, are in the same boat. We share an obligation to protect the earth in order to protect ourselves and to sustain future generations. It requires an act of faith to believe that the voyage that lies ahead will be enjoyable, bringing new technologies strikingly superior to those we have now and greater well-being. The odds are better, however, if we pursue the kinds of middle-building that reveal our common risks. I find hope in the possibility that confronting climate change collectively will gradually create a global identity that transcends our rampant tribalism.

The story has just begun.

AUTHOR'S NOTE

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All opinions and outright mistakes are mine alone.

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