DAVID GARMAN
KERRY EMANUEL
BRUCE PHILLIPS

Breaking the Climate Deadlock

Developing a broad and effective portfolio of technology options could provide the common ground on which conservatives and liberals could agree.

The public debate over climate policy has become increasingly polarized, with both sides embracing fairly inflexible public positions. At first glance, there appears little hope of common ground, much less bipartisan accord. But policy toward climate change need not be polarizing. Here we offer a policy framework that could appeal to U.S. conservatives and progressives alike. Of particular importance to conservatives, we believe, is the idea embodied in our framework of preserving and expanding, rather than narrowing, societal and economic options in light of an uncertain future.

This article reviews the state of climate science and carbon-free technologies and outlines a practical response to climate deadlock. Although it may be difficult to envision the climate issue becoming depoliticized to the point where political leaders can find common ground, even the harshest positions at the polar extremes of the current debate need not preclude the possibility.

We believe that a close look at what is known about climate science and the economic competitiveness of low-carbon/carbon-free technologies—which include renewable energy, advanced energy efficiency technologies, nuclear energy, and carbon capture and sequestration systems (CCS) for fossil fuels—may provide a framework that could even be embraced by climate skeptics willing to invest in technology innovation as a hedge against bad climate outcomes and on behalf of future economic vitality.

Most atmospheric scientists agree that humans are contributing to climate change. Yet it is important to also recognize that there is significant uncertainty regarding the pace, severity, and consequences of the climate change attributable to human activities; plausible impacts range from the relatively benign to globally catastrophic. There is also tremendous uncertainty regarding short-term and regional impacts, because the available climate models lack the accuracy and resolution to account for the complexities of the climate system.

Although this uncertainty complicates policymaking, many other important policy decisions are made in conditions of uncertainty, such as those involving national defense, preparation for natural disasters, or threats to public health. We may lack a perfect understanding of the plans and capabilities of a future adversary or the severity and location of the next flood or the causes of a new disease epidemic, but we nevertheless invest public resources to develop constructive, prudent policies and manage the risks surrounding each.

Reducing atmospheric concentrations of greenhouse gases (GHGs) would require widespread deployment of carbon-free energy technologies and changes in land-use practices. Under extreme circumstances, addressing climate risks could also require the deployment of climate remediation technologies such as atmospheric carbon removal and solar radiation management. Unfortunately, leading carbon-free electric technologies are currently about 30 to 290% more expensive on an unsubsidized basis than conventional fossil fuel alternatives, and technologies that could remove atmospheric carbon from the atmosphere or mitigate climate impacts are mostly unproven and some may have dangerous consequences. At the same time, the pace of technological change in the energy sector is slow; any significant decarbonization will unfold over the course of decades. These are fundamental hurdles.

It is also reasonably clear, particularly after taking into account the political concerns about economic costs, that widespread deployment of carbon-free technologies will not take place until diverse technologies are fully demonstrated at commercial scale and the cost premium has been reduced to a point where the public views the short-term political and economic costs as being reasonably in balance with plausible longer-term benefits.

Given these twin assessments, we propose a practical approach to move beyond climate deadlock. The large cost premium and unproven status of many technologies point to a need to focus on innovation, cost reduction, and successfully demonstrating multiple strategically important technologies at full commercial scale. At the same time, the uncertainty of long-term climate projections, together with the 1000+ year lifetime of CO2 in the atmosphere, argues for a measured and flexible response, but one that can be ramped up quickly.

This can be done by broadening and intensifying efforts to develop, fully demonstrate, and reduce the cost of a variety of carbon-free energy and climate remediation technologies, including carbon capture and sequestration and advanced nuclear, renewable, and energy efficiency technologies. In addition, atmospheric carbon removal and solar radiation management technologies should be carefully researched.

Conservatives have typically been strong supporters of fundamental government research, as well as technology development and demonstration in areas that the private sector does not support, such as national security and health. Also, even the most avowed climate skeptic will often concede that there are risks of inaction, and that it is prudent for national and global leaders to hedge against those risks, just as a prudent corporate board of directors will hedge against future risks to corporate profitability and solvency. Moreover, increasing concern about climate change abroad suggests potentially large foreign markets for innovative energy technologies, thus adding an economic competitiveness rationale for investment that does not depend on one's assessment of climate risk.

Some renewed attention is being devoted to innovation, but funding is limited and the scope of technologies is overly constrained. Our suggested policy approach, in contrast, would involve a three- to fivefold increase in R&D and demonstration spending in both the public and private sectors, including possible new approaches that involve more than simply providing the funding through traditional channels such as the Department of Energy (DOE) and the national labs.

Investing in the development of technology options is a measured, flexible approach that could also shorten the time needed to decarbonize the economy. It would give future policymakers more opportunities to deploy proven, lower-cost technologies, without the commitment to deploy them if they turn out to be unnecessary, ineffective, or uneconomic. And with greater emphasis on innovation, it would allow technologies to be deployed more quickly, broadly, and cost-effectively, which would be particularly important if impacts are expected to be rapid and severe.

In addition to research, development, and demonstration (RD&D), new policy options to support technology deployment should be explored. Current deployment programs principally using the tax code have not, at least to date, successfully commercialized technologies in a widespread and cost-effective manner or provided strong incentives for continued innovation. New approaches are necessary.

Climate knowledge

Although new research constantly adds to the state of scientific knowledge, the basic science of climate change and the role of human-generated emissions have been reasonably well understood for at least several decades. Today, most climate scientists agree that human-caused warming is underway.

Some of the major areas of agreement include the following:

- GHGs, which include water vapor, carbon dioxide (CO_2), and other gases, trap heat in the atmosphere and warm the earth by allowing solar radiation to pass largely unimpeded to the surface of the earth and re-radiating a portion of the thermal radiation received from the earth back toward the surface. This is the "greenhouse effect."
- Paleoclimatology, which is the study of past climate conditions based on the geologic record, shows that changing levels of GHGs in the atmosphere have been associated with climatic change as far back as the geological record extends.
- The concentration of CO_2 in the atmosphere has increased from about 280 parts per million (ppm) in preindustrial times to about 400 ppm today, an increase of 43%. Ice core records suggest that the current level is higher than at any time over at least the past 650,000 years, whereas analysis of marine sediments suggests that CO_2 levels have not been this high in at least 2.1 million years.
- Human-made (anthropogenic) CO_2 emissions, primarily resulting from the consumption of fossil fuels, are probably responsible for much of the warming observed in recent decades. Climate scientists attempting to replicate climate patterns over the past 30 years have not been able to do so without accounting for anthropogenic GHGs and sulfate aerosols.
- CO_2 emissions are also contributing to increases in surface ocean acidity, which degrades ocean habitats, including important commercial fisheries.
- Given the current rate of global emissions, atmospheric concentrations of CO_2 could reach twice the preindustrial level within the next 50 years; concentration levels our planet has not experienced in literally millions of years.
- The global climate system has tremendous inertia. Due to the persistence of CO_2 in the atmosphere and the oceans, many of the effects of climate change will not diminish naturally for hundreds of years if not longer.

About these basic points there is little debate, even from those who believe that the risks are not likely to be severe. Indeed, it is also true that long-term climate projections are subject to considerable uncertainty and legitimate scientific debate. The fundamental complexity of the climate system, in particular the feedback effects of clouds and water vapor, is the most important contributor to uncertainty. Consequently, long-term projections reflect considerable uncertainty in how rapidly, and to what extent, temperatures will increase over time. It is possible that the climate will be relatively slow to warm and that the effects of warming may be relatively mild for some time. But there is also a worrisome likelihood that the climate will warm too quickly for society to adapt and prosper—with severe or perhaps even catastrophic consequences.

Unfortunately, we should not expect the range of climate projections to narrow in a meaningful way soon; policymakers may hope for the best but must prepare for the worst.

Technology readiness

Under the best of circumstances, the risks associated with climate uncertainties could be managed, at least in part, with a mix of today's carbon-free energy and climate remediation technologies. Carbon-free energy generation, as used in this paper, includes renewable, nuclear, and carbon capture and sequestration systems (CCS) for fossil fuels such as coal and natural gas. Climate remediation technologies (often grouped together under the term "geoengineering") include methods for removing greenhouse gases from the atmosphere (such as air capture), as well as processes that might mitigate some of the worst effects of climate change (such as solar radiation management). We note that energy efficiency or the pursuit of greater energy productivity is prudent even in the absence of climate risk, so it is particularly important in the face of it. Although this discussion focuses on electric generation, any effective decarbonization policy will also need to address emissions from the transportation sector; the residential, commercial, and industrial sectors; and land use. Similar frameworks, focused on expanding sensible options and hedging against a worst-case future, could be developed for each.

To be effective, carbon-free and climate remediation technologies and processes need to be economically viable, fully demonstrated at scale (if they have not yet been), and be capable of global deployment in a reasonably timely manner. Moreover, they would also need to be sufficiently diverse and economical to be deployed in varied regional economies across the world, ranging from the relatively low-growth developed world to the rapidly growing developing nations, particularly those with expanding urban centers such as China and India.

The list of strategically essential climate technologies is not long, yet each of these technologies, in its current state of development, is limited in important ways. Although their status and prospects vary in different regions of the world, they are either not yet fully demonstrated, not capable of rapid widespread global deployment, or unacceptably expensive relative to conventional energy technologies. These limitations are well documented, if not widely recognized or acknowledged. The limitations of current technologies can be illustrated by quickly reviewing the status of a number of major electricity-generating technologies.

Onshore wind and some other renewable technologies such as solar photovoltaic (PV) have experienced dramatic cost reductions over the past three decades, and the percentage of installed worldwide generating capacity represented by these technologies has been growing. However, because ground-level winds are typically intermittent, wind turbines cannot be relied on to generate electricity whenever there is electrical demand, and the amount of generating output cannot be directly controlled in response to moment-by-moment changes in electric demand and the availability of other generating resources. As a consequence, wind turbines do not produce electrical output of comparable economic value to the output of conventional generating resources such natural gas–fired power plants that are, in energy industry parlance, both "firm" and "dispatchable." Furthermore, the cost of a typical or average onshore wind project in the United States, without federal and state subsidies, although now less than that of new pulverized coal plants, is still substantially more than a new gas-fired combined-cycle plant, which is generally considered the lowest-cost conventional resource in most U.S. power markets. Solar PV also suffers from its intermittency and variability, and significant penetration of solar PV can test grid reliability and complicate distribution system operation, as we are now seeing in Germany. Some of these challenges can be overcome with careful planning and coordinated execution, but the scale-up potential and economics of these resources could be improved substantially by innovations in energy storage, as well as technological improvements to increase renewables' power yield and capacity factor.

Current light-water nuclear power technology is also more expensive than conventional natural gas generation in the United States, and suffers from safety concerns, waste disposal challenges, and proliferation risks in some overseas markets. Further, given the capital intensity and large scale of today's commercial nuclear plants (which are commonly planned as two 1,000–megawatt (MW)—generating units), the total cost of a new nuclear plant exceeds the market capitalization of many U.S. electric utilities, making sole-ownership investments a "bet-the-company" financial decision for corporate management and shareholders. Yet recent improvements in costs have been demonstrated in overseas markets through standardized manufacturing processes and economies of scale; and many new innovative designs promise further cost reductions, improved safety, a smaller waste footprint, and less proliferation risk.

CCS technology is also limited. Although all major elements of the technology have been demonstrated successfully, and the process is used commercially in some industrial settings and for enhanced oil recovery (EOR), it is only now on track to being fully demonstrated at two commercial-scale electric generation facilities under construction, one in the United States and one in Canada. And deploying CCS on existing electric power plants would reduce generation efficiency and increase production costs to the point where such CCS retrofits would be uneconomic today without large government incentives or a carbon price higher than envisioned in recent policy proposals.

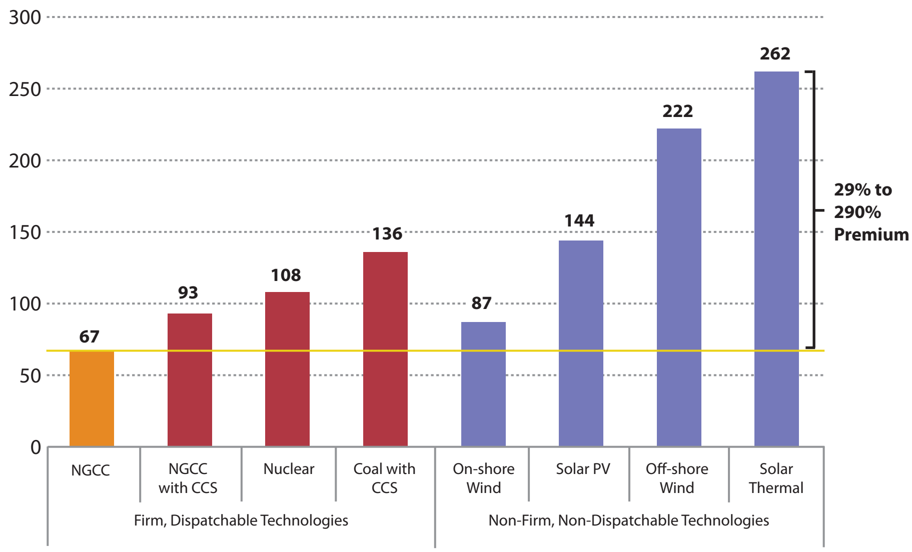
The cost premium of these carbon-free technologies relative to that of conventional natural gas–fired combined cycle technology in the United States is illustrated in the next chart.

As shown, the total levelized cost of new natural gas combined-cycle generation over its expected operating life is roughly $67/MWh (MWh, megawatt-hour). In contrast, typical onshore wind projects (without federal and state subsidies and without considering the cost of backup power and other grid integration requirements) cost about $87/MWh. New gas-fired combined-cycle plants with CCS cost approximately $93/MWh and nuclear projects about $108/MWh. New coal plants with CCS, solar PV, and offshore wind projects are yet more costly. Taken together, these estimates generally point to a cost premium of $20 to $194/MWh, or 29 to 290%, for low carbon generation.

Some may argue that this cost premium is overstated because it does not reflect the cost of the carbon externality. This would be accurate from a conceptual economic perspective, but from a commercial or customer perspective, it is understated because it doesn't account for the substantial costs of providing backup or stored power to overcome intermittency problems. The practical effect of this cost difference remains: However the cost premium might be reduced over time (whether through carbon pricing, other forms of regulation, higher fossil fuel prices, or technological innovation), the gap today is large enough to constitute a fundamental impediment to developing effective deployment policies.

This is evidenced in the United States by the wind industry's continued dependence on federal tax incentives, the difficulty of securing federal or state funding for proposed utility-scale CCS projects, the slow pace of developing new nuclear plants, and the recent controversies in several states proposing to develop new offshore wind and coal gasification projects. The inability to pass federal climate legislation can also be seen as an indication of widespread concern about the cost of emissions reductions using existing technologies, the effectiveness of the legislation in the global long-term context, or both.

U.S. average levelized costs for new plants entering service in 2018 ($/MWh)



Source: EIA LCOE in AEO 2013

Cost considerations are even more fundamental in the developing world, where countries' overriding economic goal is to raise their population's standard of living. This usually requires inexpensive sources of electricity, and technologies that are only available at a large cost premium are unlikely to be rapidly or widely adopted.

Although there is little doubt that there are opportunities to reduce the cost and improve the performance of today's technologies, the history of technological transformation in the energy sector is typically slow, unpredictable, and incremental because it widely employs long-lived capital-intensive production and infrastructure assets tied together through complex global industries—characteristics contributing to tremendous inertia. Engineering breakthroughs are rare, and new technologies typically take many decades to reach maturity at scale, sometimes requiring the development of new business models. As described by Arnulf Grubler and Nebojsa Nakicenovic, scholars at the International Institute for Applied Systems Analysis (IIASA), the world has only made two "grand" energy transitions: one from biomass to coal between 1850 and 1920, and a second from coal to oil and gas between 1920 and today. The first transition lasted roughly 70 years; the second has now lasted approximately 90 years.

A similar theme is seen in the electric generating industry. In the 130 years or so since central generating stations and the electric lightbulb were first established, only a handful of basic electric generating technologies have become commercially widespread. By far the most common of these is the thermal power station, which uses energy from either the combustion of fossil fuels (coal, oil, and gas) or a nuclear reactor to operate a steam turbine, which in turn powers an electric generator.

The conditions that made energy system transitions slow in the past still exist today. Even without political gridlock, it could well take many decades to decarbonize the global energy sector, a period of time that would produce much higher atmospheric concentrations of CO_2 and ever-growing greater risks to society. This points to the importance of beginning the long transition to decarbonize the economy just as soon as possible.

Policy implications

Given the uncertainties in climate projection, innovation, and technology deployment, developing a broad range of technology options can be a hedge against climate risk.

Technology "options" (as the term is used here) include carbon-free technologies that are relatively costly or not fully demonstrated but with innovation through fundamental and applied RD&D might become sufficiently reliable, affordable, and scalable to be widely deployed if and when policymakers determine they are needed. (They are not to be confused with other technologies, such as controls for non-CO2 GHGs such as methane and niche EOR applications of fossil CCS, which have already been commercialized.)

A technology option is analogous to a financial option. The investment to create the technology is akin to the cost of buying the financial option; it gives the owner the right but not the obligation to engage in a later transaction.

Examples of carbon-free generation options include small modular nuclear reactors (SMRs) or advanced Generation IV nuclear reactor technologies such as sodium or gas-cooled fast reactors; advanced CCS technologies for both coal and natural gas plants; underground coal gasification with CCS (UCG/CCS); and advanced renewable technologies. Developing options on such technologies (assuming innovation success) would reduce the cost premium of decarbonization, the time required to decarbonize the global economy, and the risks and costs of quickly scaling up technologies that are not yet fully proven.

In contrast to carbon-free generation, climate remediation options could directly remove carbon from the atmosphere or mitigate some of its worst effects. Examples include atmospheric carbon removal technologies (such as air capture and sequestration, regional or continental afforestation, and ocean iron fertilization) and solar radiation management technologies (such as stratospheric aerosol injection and cloud-whitening systems.) Because these technologies have the potential to reduce atmospheric concentrations or global average temperatures, they could (if proven) reduce, reverse, or prevent some of the worst impacts of climate change if atmospheric concentrations rise to unacceptably high levels. The challenge with this category of technologies will be to reduce the cost and increase the scale of application while avoiding unintended environmental and ecosystem harms that would offset the benefits they create.

Again, investing now in the development of such technology options would not create an obligation to deploy them, but it would yield reliable performance and cost data for future policymakers to consider in determining how to most effectively and efficiently address the climate issue. That is the essence of an iterative risk management process. Such a portfolio approach would also position the country to benefit economically from the growing overseas markets for carbon-free generation and other low-carbon technologies. It also addresses the political and economic polarization around various energy options, with some ideologies and interests focused on renewables, others on nuclear energy, and still others on CCS. A portfolio approach not only hedges against future climate uncertainties but also offers expanded opportunities for political inclusiveness and economic benefit. Over a period of time, investments in new and expanded RD&D programs would lead to new intellectual property that could help grow investments, design, manufacturing, employment, sales, and exports to serve overseas and perhaps domestic markets.

This portfolio approach would be a significant departure from current innovation and deployment policies. Although new attention is being devoted to energy innovation, including DOE's Advanced Research Projects Agency–Energy (ARPA-E), the scope of technologies is far too constrained. For instance, despite its importance, a fully funded program to demonstrate multiple commercial-scale post-combustion CCS systems for both coal and natural gas generating technologies has yet to be established. Similarly, efforts to develop advanced nuclear reactor designs are limited, and there is almost no government support for climate remediation technologies. Renewable energy can make a large contribution, but numerous studies have demonstrated that it will probably be much more difficult and costly to decarbonize our electricity system within the next half century without CCS and nuclear power.

Our approach, in contrast, would involve a broader mix of technologies and innovation programs including the fossil, advanced nuclear, advanced renewable, and climate remediation technologies to maximize our chances of creating proven, scalable, and economic technologies for deployment.

The specific deployment policies needed would depend in part on the choice of technologies and the status of their development, but they would probably encompass an expanded suite of programs across the RD&D-to-commercialization continuum, including fundamental and applied R&D programs, incentives, and other means to support pilot and demonstration programs, government procurement programs, and joint international technology development and transfer efforts.

The innovation processes used by the federal government also warrant assessment and possible reform. A number of important recent studies and reports have critiqued past and current policies and put forward recommendations to accelerate innovation. Of particular note are recommendations to provide greater support for demonstration projects, expand ARPA-E, create new institutions (such as a Clean Energy Deployment Administration, a Green Bank, an Energy Technology Corporation, Public-Private Partnerships, or Regional Innovation Investment Boards), and promote competition between government agencies such as DOE and the Department of Defense. All of these deserve further attention.

Of course there will never be enough money to do everything. That's why a strategic approach is essential. The portfolio should focus on strategically important technologies with the potential to make a material difference, based on analytical criteria such as:

- ***The likelihood of becoming "proven."*** Many if not most of the technologies that are likely to be considered options have not yet been proven to be reliable technologies at reasonable cost. Consequently, assessing this prospect, along with a time frame for full development and deployment, would obviously be an important decision criterion. This would not preclude "long-shot" technologies; rather it would ensure that their prospects for success be weighed with other criteria.
- ***Ability to reach multi-terawatt scale.*** Some projections of energy demand suggest that complete decarbonization of the energy system could require 30 terawatts of carbon-free power by mid-century, given current growth patterns.
- ***Relevance to Asia and the developing world.*** Because most of the growth in the developing world will be con-

centrated in large dense cities, distributed energy sources or those requiring large amounts of land area may have less relevance.

- ***Ability to generate firm and dispatchable power.*** Electrical demands vary widely over time, often fluctuating by a factor of 2 over the course of a single day. Because electricity needs to be generated in a reliable fashion in response to demand, intermittent resources could have less relevance under conditions of deep decarbonization, unless their electrical output can be converted into a firm resource through grid-scale energy storage systems.
- ***Potential to reduce costs within a reasonable range of conventional technologies.*** The less expensive a zero-carbon energy source is and the closer it can be managed down to cost parity with conventional resources such as gas and coal, the more likely it is that it will be rapidly adopted at scale.
- ***Private-sector investment.*** If the private sector is adequately investing in the development or demonstration of a given technology, there would be no need for duplicative government support.
- ***Potential to advance U.S. competitiveness.*** Investments should be sensitive to areas of energy innovation where the United States is well positioned to be a global leader.

To illustrate this further, programs might include the following.

1. A program to demonstrate multiple CCS technologies, including post-combustion coal, pre-combustion coal, and natural gas combined-cycle technologies at full commercial scale.
2. A program to develop advanced nuclear reactor designs, including a federal RD&D program capable of addressing each of the fundamental concerns about nuclear power. Particular attention should be given to the potential for small modular reactors (SMRs) and advanced, non–light-water reactors. A key complement to such a program would be the review and, if necessary, reform of Nuclear Regulatory Commission expertise and capabilities to review and license advanced reactor designs.
3. Augmentation of the Department of Defense's capabilities to sponsor development, demonstration, and scale-up of advanced energy technology projects that contribute to the military's national security mission, such as energy security for permanent bases and energy independence for forward bases in war zones.
4. Continued expansion of international technology innovation programs and transfer of insights from overseas manufacturing processes that have resulted in large capital cost reductions for the United States. In recent years, a number of government-to-government and business–to–nongovernmental organization partnerships have been established to facilitate such technology innovation and transfer efforts.
5. Consideration of the use of a competitive procurement model, in which government provides funding opportunities for private-sector partners to demonstrate and deploy selective technologies that lack a current market rationale to be commercialized.

Note that this is not intended to be an exhaustive list of the efforts that could be considered, but there should be consideration of new models of public-private cooperation in technology development.

The technology options approach outlined in this paper, with its emphasis on research, development, demonstration, and innovation, serves a different albeit overlapping purpose from deployment programs such as technology portfolio standards, carbon-pricing policies, and feed-in tariffs. The options approach focuses primarily on developing improved and new technologies, whereas deployment programs focus primarily on commercializing proven technologies.

RD&D and deployment policies are generally recognized as being complementary; both would be needed to fully decarbonize the economy unless carbon mitigation was in some way highly valued in the marketplace. In practice, at least to date, technology deployment programs have not successfully commercialized carbon-free technologies in a widespread, cost-effective manner, or offered incentives to continue to innovate and improve the technology. New approaches including the use of market-based pricing mechanisms such as reverse auctions and other competitive procurement methods are likely to be more flexible, economically efficient, and programmatically effective.

Yet deploying new carbon-free technologies on a widespread basis over an extended period of time will be a policy challenge until the cost premium has been reduced to a level at which the tradeoffs between short-term certain costs, and long-term uncertain benefits are acceptable to the public. Until then, new deployment programs will be difficult to establish, and if they are established, they are likely to have little material impact (because efforts to constrain program costs would lead these programs to have very limited scopes) or be quickly terminated (due to high program costs), as we have seen with, for example, the U.S. Synthetic Fuels Corporation. Therefore, substantially reducing the cost premium for carbon-free energy must be a priority for both innovation and deployment programs. It is likely to be the fastest and most practical path to create a realistic opportunity to rapidly decarbonize the economy.

Although we are not proposing a specific or complete set of programs in this paper, it is fair to say that our policy approach would involve a substantial increase in energy RD&D spending—an effort that could cost between $15 billion and 25 billion per year, a three- to fivefold increase over recent energy RD&D spending levels.

This is a significant increase over historic levels but modest compared to current funding for medical research (approximately $30 billion per year) and military research (approximately $80 billion per year), in line with previous R&D initiatives over the years (such as the War on Terror, the NIH buildup in the early 2000s, and the Apollo space program), and similar to other recent energy innovation proposals.

The increase in funding would need to be paid for, requiring redirection of existing subsidies, funding a clean energy trust from federal revenues accruing from expanded oil and gas production, a modest "wires charge" on electricity rate payers, or reallocations as part of a larger tax reform effort. We are not suggesting that this would necessarily be easy, only that such investments are necessary and are not out of line with other innovation investment strategies that the nation has adopted, usually with bipartisan support. In this light, we emphasize again the political virtues of a portfolio approach that keeps technological options open and offers additional possible benefits from the potential for enhanced economic competitiveness.

In light of the uncertain but clear risk of severe climate impacts, prudence calls for undertaking some form of risk management. The minimum 50-year time period that will be required to decarbonize the global economy and the effectively irreversible nature of any climate impacts argue for undertaking that effort as soon as reasonably possible. Yet pragmatism requires us to recognize that most of the technologies needed to manage this risk are either substantially more expensive than conventional alternatives or are as yet unproven.

These uncertainties and challenges need not be confounding obstacles to action. Instead, they can be addressed in a sensible way by adopting the broad "portfolio of technology options" approach outlined in this paper; that is, by developing a diverse array of proven technologies (including carbon capture, advanced nuclear, advanced renewable, atmospheric carbon removal, and solar radiation management) and deploying the most successful ones if and when policymakers determine they are needed.

This approach it would provide policymakers with greater flexibility to establish policies deploying proven, scalable, and economical technologies. And by placing greater emphasis on reducing the cost of scalable carbon-free technologies, it would allow these technologies to be deployed more quickly, broadly, and cost-effectively than would otherwise be possible. At the same time, it would not be a commitment to deploy them if they turn out to be unnecessary, ineffective, or uneconomical.

We believe that this pragmatic portfolio approach should appeal to thoughtful people across the political spectrum, but most notably to conservatives who have been skeptical of an "all-in" approach to climate that fails to acknowledge the uncertainties of both policymaking and climate change. It is at least worth testing whether such an approach might be able to break our current counterproductive deadlock.

David Garman, a principal and managing partner at Decker Garman Sullivan LLC, served as undersecretary in the Department of Energy in the George W. Bush administration. Kerry Emanuel is the Cecil and Ida Green Professor of atmospheric science at the Massachusetts Institute of Technology and codirector of MIT's Lorenz Center, a climate think tank devoted to basic curiosity-driven climate research. Bruce Phillips is a director of The NorthBridge Group, an economic and strategic consulting firm.