Structuring an Energy Technology Revolution

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Introduction

The environmental and geopolitical costs of America's addiction to fossil fuels make a federal program to stimulate innovation in energy technology both justifiable and essential. Such a technology supply-side program should be accompanied by policies that ensure long-term, sustained high prices for emission of carbon dioxide into the atmosphere—for example, a carbon tax or a cap-and-trade system, as well as regulatory standards and other measures to foster demand for more efficient overall energy use. But market forces alone cannot provide the pace and scope of innovations required to meet the urgent national need for improved technology for energy supply and efficient end use, and to overcome the huge built-in preferences for existing energy technologies.[1]

Our current technology supply-side efforts consist of underfunded research with an occasional tax incentive or regulatory mandate thrown in. There has been much talk and consensus about the need to introduce new energy technologies but few concrete proposals on how to actually get them into the marketplace at the scale required. Even climate change legislation now before the Congress calls for significant subsidies to existing alternatives to fossil fuels but only small sums for research, development, and deployment of the many new ideas now in active development in commercial and university laboratories.

This book gets inside the "black box" of energy innovation, looking at it as a system, and proposes answers to the problem of encouraging and stimulating the implementation of improved energy technology that has thus far eluded our political system. Given the central role of energy in the economy, a program to stimulate technological innovation in energy will need to approach the dimensions of a major military transformational effort. It must go beyond research and development (R&D) to include all aspects of the innovation process. No single technology or "silver bullet" will suffice; we will need an expanded set of options made possible by a broad range of new technology entrants.

As a working foundation for that program, we propose a new integrated analytic framework, drawing on current innovation theory, as a basis for developing technology policy for energy and comparable complex economic sectors. From that base, we set forth a new, four-step framework for the development of policy to encourage energy innovations. First, we assess energy technologies, not only for their present status and likely future development, but most importantly for the obstacles they are most likely to encounter when they eventually enter the highly competitive marketplace for energy technology. We use these assessments to categorize energy innovations according to the issues they will probably face as they are launched. Second, for each launch path, we define packages of relatively neutral policy measures, from R&D incentives to regulatory measures, designed both to bridge the "valley of death" between research and late-stage development that historically has been the most important barrier to the deployment of civilian technology, and more significantly in our view, to surmount the barriers to the implementation of technology. Third, based on this analysis, we identify several functional gaps in the present system of government institutional support for energy innovation that will hinder our ability to achieve steps 1 and 2. Fourth, we propose public- and private-sector interventions to fill these gaps. This conceptual framework may be applicable to other complex innovation system areas in addition to energy.

Another, equally important problem is the deep politicization of energy policy in the United States. For decades, the environmental wing of American politics, now tied to the political left, has urged subsidies to renewable energy—specifically to sun and wind, with notable neglect of geothermal energy. The right has been no less enthusiastic in its support of subsidies to oil, natural gas, and nuclear energy. The coal and oil industries, moreover, are protected by the congressional delegations in key states where they provide employment. Reflecting these pressures, plus a long regulatory history, the role of the government in the energy sector has long been intense and interventionist. Despite growing geopolitical and climate realities, a balanced, technology-neutral approach to energy policy has not been attempted by either political party. Today, a coherent approach to energy technology policy is still missing from the legislative policy debate in the U.S. Congress; each technology, new and old, seeks its own separate legislative deal for federal backing.

Even in the abstract, to be sure, the idea of technology neutrality has an inescapable limitation, namely, that of the choice of objective. Politics aside, a technology strategy intended to end dependence on oil from foreign sources will differ in important ways from one intended to mitigate global warming by reducing emission of carbon dioxide. To briefly summarize this now highly visible fault line in American politics, both of these approaches will favor renewable domestic sources of energy like wind, solar, and geothermal. But a policy focused exclusively on self-sufficiency in fuels for the transport sector will emphasize domestic sources, carbon-emitting or otherwise. A policy intended to limit emission of carbon dioxide and other forms of environmental damage must stress lowering carbon emissions by all appropriate means, predominantly through new technologies in addition to efficiency and conservation. Fortunately, there remains substantial overlap—the need for new technology—between the two positions.

Since the political system on all sides is now contemplating a major shift on energy policy, are the technologies we need already here? The dominant theme in much of the energy policy literature—especially by analysts inspired by the environmental costs of present patterns of energy use—has been the critical importance of carbon charges in directing the demand for energy and energy technology toward "carbon-free" sources. In response, some industry advocates have argued that carbon charges must be delayed because any major change in energy-use patterns will require breakthroughs in technology that will take time to achieve.

To forestall such criticism, other analysts have pointed to technologies that are at or near the point of readiness for full-scale exploitation and that, taken together, could stabilize atmospheric CO_2 concentrations, so that there is no need to wait for technological breakthroughs for this purpose. In a classic article, Socolow and Pacala have identified fifteen "wedges"—changes in energy use based on technologies said to be either at or near technoeconomic readiness, any seven of which, taken together, would suffice to stabilize CO_2 concentrations by midcentury.[2] Some of these changes are clearly within the range of adoption and timely scale-up. Others—reduced deforestation, a 50 percent reduction in driving by two billion vehicles, or widespread adoption of conservation tillage, for example—would, as the two authors recognize, require major changes in policy and behavior that could take extended periods. Still others, like technology for carbon capture and sequestration, are likely to take years of development and demonstration before they are ready for widespread deployment.

Other policy analyses of climate change and energy security recommend a major effort to effect new technology, although this recommendation often comes almost as an afterthought after a long discussion of carbon charges.[3] (As summarized in chapter 5, the relatively few analyses specifically concerned with energy R&D typically recommend large increases, but most of these reach more specialized audiences.) The Intergovernmental Panel on Climate Change (IPCC), for example, concurs that a portfolio of new technologies can yield CO_2 stabilization, "assuming appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers."[4] Beyond this assertion, the processes by which the technologies might be developed, deployed, and diffused have been left largely unstudied.

In sum, technological alternatives to fossil fuels do exist or can be realized.[5] But few are technically or economically ready for deployment on the huge scale needed to make a dent in the demand for fossil fuels. Some are operating on a limited commercial scale, while others now exist only in the laboratory. To cite a few examples of what we can see today, solar photovoltaics are still too expensive, carbon capture and sequestration require prototyping and validation at a huge scale, batteries must realize further materials and cost advances, and fuel cells for transport applications face years of experimentation. Aside from the major research needed to keep rolling out advances for these technologies to cut costs and improve efficiencies, there is a need for ongoing research to seek breakthroughs, especially if we decide we need to go beyond stabilizing the carbon dioxide concentration in the atmosphere at current levels by midcentury. For example, two recent economic evaluations have called for reductions from

1990 levels from 25 percent to 60–80 percent,[6] and the G-8 nations agreed in principle in July 2008 to halve greenhouse gas emissions by midcentury from current levels.[7]

Taken together, these technologies will still require massive investment, involving extensive collaboration between business, government, and universities.[8] What is more, the requirements for the development and deployment of these technologies on a scale sufficient to address the problem of global warming, not to mention the economic and geopolitical costs of dependence on foreign oil, amount to no less than a new *technological/economic/political paradigm* for energy.[9] This new paradigm will involve new technologies backed by policies, regulations, incentives, technology institutions, and public understanding and support. This vast and varied array of new technology will take many decades and many generations of technical innovation to evolve and be adopted on the necessary scale.[10] It would be a serious mistake to concentrate exclusively on short-term technological solutions to the neglect of these more far-reaching approaches.

The problem of climate change is global, so that the new paradigm will need to be global. Even so, technology advance still largely follows a nation-state model.[11] Although multinational corporations are moving the development stage toward international collaboration, other key features of innovation systems, such as research funding, science and technical education, and publicly funded research institutions, remain rooted in national funding and support.[12] The U.S. innovation system has led world technology waves for many decades,[13] and despite the rapid rise of capabilities in other countries, there is no easy substitute for its technology leadership in this arena.[14] There is a trade-off between the need to share technology in order to work together to meet a common danger and to benefit from the exchange of knowledge, on the one hand, and the need to provide incentives to industry to gain competitive advantage through innovation and capacity building, on the other. The United States should keep in mind, too, that the economic advantages of leadership in technology have been the source of its wealth and well-being. Is it really in America's interest to cede leadership of a technological revolution in energy to other countries that now also understand the innovation-based growth model?

Demand-Side Measures by Themselves Will Be Insufficient

Private investment in research on alternatives to fossil fuels is discouraged by the history of wild oscillations in the price of energy. A barrel of oil may cost about $60 as these words are written in the fall of 2008, but it cost more than $140 in the summer of 2008 and less than $20 in 1998.[15] If energy companies were convinced that $100-a-barrel oil were here to stay, some would see the long-term business wisdom of major investments to diversify their raw materials and their technologies, despite their current high profit levels. As things now stand, however, many of them remain opposed, skeptical, or at best ambivalent. Yet there are clear indications that, unlike the price spike induced by the oil embargo of the 1970s, increasing energy prices are predominantly due to a significant rise in world demand from developed and particularly emerging economies.[16]

Here we distinguish between the demand for energy itself, and the demand for improved energy technology. The two are related but are not the same. In the short term, carbon charges or high energy prices will reduce the immediate demand for fossil fuels or energy, respectively. Demand for improved or alternative energy technology, on the other hand, will be created only if these prices are seen as likely to be sustained. We may similarly distinguish between the supply of energy technology and the supply of energy itself; our focus is on the former.

The single policy that would be most effective in stimulating such research, then, would be a sustained policy that stimulates demand for both energy conservation and energy technology. This could come about by ensuring either the high energy prices[17] supported by some focused on energy security, or a high cost of carbon dioxide (and other greenhouse gas) emissions supported by those focused on climate change, or both, for the next few decades[18]—the latter either through a direct carbon tax[19] on CO_2 emissions (known in the literature as a "carbon charge") or equivalently, through a cap-and-trade scheme. The political consensus needed to support at least cap-and-trade policies is stirring and could be reached in the next few years.[20] However, as we will see in later chapters, there is a real possibility of adopting a deeply flawed system because of political pressures from various interest groups.[21]

Even with such energy prices or carbon charges, private capital will not suffice to stimulate technological innovation without major public support.[22] As economist Jeffrey Sachs has noted,

> Technology policy lies at the core of the climate change challenge. Even with a cutback in wasteful energy spending, our current technologies cannot support both a decline in carbon dioxide emissions and an expanding global economy. If we try to restrain emissions without a fundamentally new set of technologies, we will end up stifling economic growth, including the development prospects for billions of people. Economists often talk as though putting a price on carbon emissions through tradable permits or a carbon tax will be enough to deliver the needed reductions in those emissions. This is not true. . . . We will need much more than a price on carbon. Consider three potentially transformative low-emissions technologies: carbon capture and sequestration (CCS), plug-in hybrid automobiles and concentrated solar-thermal electricity generation. Each will require a combination of factors to succeed: more applied scientific research, important regulatory changes, appropriate infrastructure, public acceptance and early high-cost investments. A failure on one or more of these points could kill the technologies.[23]

An innovation system must be stimulated by market demand for improved technology, but workable policies to stimulate this demand still presuppose a strong innovation system. What is more, most new energy technologies face a dense network of political traps in the United States because of the huge scale of deployment required, because of the deeply entrenched, price-efficient competitors, and because of the economic interests, policies, and public attitudes that support the old, fossil-fuel-based paradigm.

Ideally, then, economics and technology would develop together. Major supply-side technology development programs would be coupled with policies that create a demand pull for improved energy technology through assured, sustained, high carbon energy prices, incentives for conservation and for the entry of new energy sources, and penalties for wasteful use. This mix would feature public-sector investment leveraging private capital at scale and vice versa.

Presidents since the 1970s have been calling for U.S. energy security, but the record on this issue constitutes one of the greatest public policy failures in our history. Part of this story is the level of investment. Federal support for energy R&D has fallen by more than half since a high point in 1980, and private-sector energy R&D has similarly fallen. These levels of expenditure compare poorly to other major federal R&D efforts that met challenges of similar magnitude: the Manhattan Project, the Apollo Project, the Carter-Reagan defense buildup, and the doubling of the budget of the National Institutes of Health.[24] Advances in energy technology will not occur on the scale required without significantly increased investment by both government and business.

We are optimistic that a public consensus in favor of policies creating a demand for technological innovation will in fact take shape. In the meantime, can we begin to create a new paradigm? If such policies are to elude us for a time, can we at least start down available pathways for R&D and put as many technology supply-oriented policies in place as possible in accordance with a coherent strategy? Regardless of when a technology demand-side program is initially imposed, developing a sound innovation system for energy technology will show industry that the transition to alternative energy technologies is feasible, not the pie in the sky they fear, and in this way will help to defuse political opposition to the sound demand-oriented policies that will also be needed to effect the needed energy transition.

A supply-side technology development strategy for energy would have to be structured quite differently from government-led technology development projects like the Manhattan Project or the Apollo Moon Mission. These projects developed and implemented single-focus technologies in comparatively short-term projects for the government, a single customer with deep pockets. They were managed and executed by unified organizations within the federal government. Energy challenges require a very different development model, in which a complex mix of energy technologies must evolve over decades in the private sector. Given the complexity and unpredictability of this evolution, the resulting innovation system should be technology-neutral to the extent possible.

This is perhaps the most complex technology evolution problem the United States has ever faced. It makes getting to the moon start to look simple by comparison. A coherent strategy will be vital; we aim in this work to begin a discussion of the elements that will be required in such a strategy. Different "front-end" research, development, and demonstration policies, and different sets of "back-end" incentives and, in some cases, regulatory mandates, for implementation and deployment will be needed at different times for different kinds of technology. These policies will depend on the present state of development of the technology, the likely path by which it will be launched into the marketplace, the level of economic competition and political opposition it is likely to stimulate, and the availability of a sound, complementary demand-side pricing system.

Public intervention should spur and support the private sector, with the objective of speeding the development and deployment of a broad range of future energy technology options considerably faster than would be expected from market forces alone. While it is impossible to say which of the many promising energy technologies will come to full fruition, a conservative list would include: fully competitive technology for the production of electricity from wind and sun, plug-in hybrid cars with performance and range comparable to those of contemporary cars but with several times the gas mileage; a "smart grid" that is both far more efficient and can accommodate renewables; reliable and well-characterized technology for enhanced geothermal energy and for carbon capture and sequestration; lighting technologies with twice the efficiency of present-day fluorescent lights; dramatically more efficient buildings, new nuclear technologies if waste storage, safety, diversion, and proliferation issues can be satisfied; and improved manufacturing technologies for a wide variety of energy technologies to lower costs and improve quality.

There will be some who argue from a market economics perspective that a cap-and-trade policy or carbon tax will internalize carbon externalities, while high energy prices will discourage energy use, so that demand pull will be enough to foster new technologies. We believe this fails to fully take into account the realities of the government's extensive intervention underwriting the existing system, and the need to accelerate the pace of technology introduction. An old story about the economics profession is relevant here. A bus is traveling along the California coast packed with neoclassical economists attending a convention. They are accompanied by one reporter. Suddenly, the bus crashes through the guardrail over a 300-foot cliff toward the sea. The reporter starts screaming, but the economists are all silent. The reporter asks the economist seated next to him why he and his colleagues are not screaming since death is imminent. The economist responds, "My friend, there is so much pent-up demand that a parachute will appear."

This book argues that someone should be working on the parachute to feed the pent-up demand. It seeks a strategy for parachute creation and implementation.