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The Road to a New Energy System:

Stimulating Innovation in Energy Technology

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Meeting the world's urgent need for a cleaner and more efficient energy system will require a more effective strategy that incorporates technology neutrality, international collaboration, institutional change, and a more fine-tuned understanding of the innovation process.

Energy technology poses a special challenge to the U.S. innovation system. Fossil fuels are deeply imbedded in the economy and the political system. To the user, they are usually cheap, convenient, efficient, and available in huge quantities. They benefit from public investments in infrastructure as well as direct subsidies through the tax system. The industries that produce and sell them are major employers and benefit from the public expectation of low-cost and readily available energy. New energy technologies seeking to enter the marketplace thus face a far from level playing field.

But fossil fuels, of course, are not really cheap; their economic, environmental, and geopolitical costs place a heavy burden on the nation. The effort to reduce this burden amply justifies a program of the size and scope, although not the form, of the Manhattan Project, the Marshall Plan, or the Apollo Project. President

Obama's $39 billion energy stimulus program and his April address to the National Academy of Sciences make it clear that he regards support for innovation in energy technology as an essential element of this administration's efforts to deal with the country's addiction to fossil fuels. It constitutes a recognition that market forces alone, even if augmented by a carbon charge or cap-and-trade regime, will not generate the pace and scope of innovations in energy supply and efficient end use that are needed to overcome the huge built-in preferences for existing energy technologies.

For the past several decades, the nation's investment in energy technology research has been pathetically inadequate compared to the $1.5 trillion that the energy sector contributes to the U.S. economy. Public-sector funding fell by half between its peak in 1980 and 2005, and private-sector funding has followed a similar path. Even the 2005–2008 flood of venture capital was directed in significant part to investments in existing technologies that are already benefiting from subsidies supported by powerful interest groups in spite of their dubious environmental or economic value—a "no lobbyist left behind" policy that runs counter to the urgent need for innovation leading to a sustainable energy future.

This underfunding of research, combined with the oscillating prices of energy and the history of subsidies to politically favored technologies (renewable energy for Democrats, nuclear power and fossil fuels for Republicans, coal for both), has left a multitude of technologies at all stages of development. These need to be given a chance to emerge, but no single technology has any special claim on support. This means that innovation policies need to be as technology-neutral as possible so that technological alternatives can compete on their own technoeconomic merits.

An integrated analysis

The most difficult step in the development and deployment of new technology in energy will be the launch of these technologies into extremely complex and competitive markets of enormous scale. Any program of government support for innovations in these technologies should therefore be organized around the most likely bottleneck to their introduction to the market. This goes well beyond the longstanding focus of government programs on basic research and the "valley of death" between research and late-stage development.

We therefore advocate an integrated consideration of the entire innovation process, including research, development, deployment, and implementation, in the design of policies to encourage innovation in energy technology. Only such an overview will make it possible to identify gaps in existing federal institutions for the support of the overall process of innovation. Such an examination is an essential element in the design of any program to stimulate innovation in energy or in any other complex established technology.

These considerations have led us to a new framework for innovation policy in complex established technology areas. It requires a four-step gap analysis: classifying promising innovations according to likely obstacles to their market launch, identifying policies needed to overcome these obstacles, identifying gaps in existing institutions and programs that prevent them from overcoming these obstacles, and recommending new institutions or policies to fill these gaps. We believe that a similar approach is likely to be a useful starting point for the design of innovation policy in sectors of comparable complexity to energy. Although the problem of the valley of death remains important, the analytical framework we suggest helps to evaluate and overcome an even larger problem in such complex sectors: the stage of market launch.

The first step of this analysis is the assessment of a large number of promising energy technologies, based on the likely bottlenecks in their launch path, and the classification of these technologies into groups that share the same likely obstacles to market launch. A complex sector such as energy is home to a great range of established and potential technologies in a variety of separate or connected market sectors. Each technology will follow a different route to emergence at scale, but some may share common features. Categorizing common technology-emergence pathways allows the design of support instruments appropriate to each category; without rigorous and careful categorization, workable support mechanisms will simply not emerge, and gaps in and barriers to implementation are inevitable. With this in mind, we have identified the following energy technology pathways:

- *Experimental technologies*. This category includes technologies requiring extensive long-range research. The deployment of these technologies is sufficiently far off that the details of their launch pathways can be left to the future. Examples include hydrogen fuel cells for transport; genetically engineered biosystems for CO2 consumption; and, in the very long term, fusion power.
- *Potentially disruptive technologies*. These are innovations that can be launched in niche markets that are apart from established systems. In these markets, such innovations face limited initial competition, may expand from this base as they become more price-competitive, and can then challenge established incumbent or "legacy" technologies. Examples include wind and solar technologies, which are building niches in off-grid power and LED lighting.
- *Secondary technologies (uncontested launch)*. This group includes secondary (component) innovations that will face market competition immediately on launch from established component technologies that perform more or less the same function. These innovations can be expected to be acceptable to recipient industries if the price is right. On the other hand, they must face the rigors of the tilted playing field, such as a competing subsidy, or the obstacle of a major cost differential without the advantage of an initial niche market. Examples include advanced batteries for plug-in hybrids, enhanced geothermal, and on-grid wind and solar.
- *Secondary technologies (contested launch)*. These are secondary innovations that in addition to facing the same barriers as the

uncontested technologies have inherent cost disadvantages and/or can be expected to face economic, political, or other nonmarket opposition from recipient industries or environmental groups. Examples include carbon capture and sequestration, biofuels, and fourth-generation nuclear power.

- *Incremental innovations in conservation and end-use efficiency*. The implementation of these innovations is limited by the short time horizons of potential buyers and users, who typically refuse to accept extra initial costs unless the payback period is very short. Examples include improved internal combustion engines, improved building technologies, efficient appliances, improved lighting, and new technologies for electric power distribution.
- *Improvements in manufacturing technologies and processes*. These are improvements in the ways in which products are manufactured that can drive down costs and improve efficiency, enabling the new products to compete in the market more quickly. These investments are likely to be inhibited by the reluctance of cautious investors to accept the risk of increasing production capacity and driving down manufacturing costs in the absence of an assured market.

The second step of our analysis requires classifying support policies for the encouragement of energy innovation into technology-neutral packages and matching them to the technology groupings developed in the first step. In other words, once we have identified the different launch pathways by which new technologies can arrive in a market at scale, we can match them with the best support policies. The policy elements include:

- *Front-end technology nurturing*. Technology support on the innovation front end, before a technology is close to commercialization, is needed for technologies in all six categories above on the technology-launch pathway. This includes direct government support for long- and short-term R&D, technology prototyping, and demonstrations.
- *Back-end incentives*. Incentives (carrots) to encourage

technology transition on the back end as a technology closes in on commercialization may be needed to close the price gap between emerging and incumbent technologies. Whereas experimental technologies are in too early a stage to need incentives, and many disruptive technologies may be able to emerge out of technology niches into a competitive position without further incentives beyond R&D support, other categories will probably require carrots. These include secondary technologies facing both uncontested and contested launch, incremental innovations in technology for conservation and end use, and technologies for manufacturing processes and scale-up. Carrots may also be relevant to some disruptive technologies as they transition from niche areas to more general applicability. These incentives include tax credits of various kinds for new energy technology products, loan guarantees, low-cost financing, price guarantees, government procurement programs (including military procurement for quasi-civilian applications such as housing), new-product buy-down programs, and general and technology-specific intellectual property policies.

- *Back-end regulatory and related mandates*. Regulatory and related mandates (sticks), also on the back end, may be needed in order to encourage component technologies that face contested launch and also some conservation and end-use technologies. These include standards for particular energy technologies in the building and construction sectors, regulatory mandates such as renewable portfolio standards and fuel economy standards, and emission taxes.

In the energy sector, a system of carbon charges, such as a cap-and-trade program, may make many of the back-end proposals listed above less necessary insofar as it would induce similar effects through pricing mechanisms.

The third step is an institutional gap analysis that consists of a survey of existing institutional and organizational mechanisms for the support of innovation, with the objective of determining what kinds of innovations (as classified by the likely bottlenecks in their launch paths) do not receive federal support at critical stages of the innovation process and what kind of support mechanisms are needed to fill the gaps thus identified.

The fourth step identifies new institutions and organizational mechanisms needed to fill these gaps in the institutions for the promotion of innovation that were identified in the third step; namely, those needed for translational research, for technology financing, and for roadmapping.

Institutional gaps

Our analysis identified at least four separate gaps in current institutional arrangements for the promotion of energy innovation. First, there has been no strong program in the Department of Energy or elsewhere that is explicitly devoted to translational research. By this we mean supporting breakthrough research tied to needed energy technologies and then translating the technologies that derive from the breakthroughs to the prototype stage in a connected and integrated fashion and with commercialization in mind.

A second gap concerns the financing and management of commercial demonstrations of large-scale, engineering-intensive technologies with careful monitoring to ascertain technical feasibility, environmental performance, safety, and costs. Such demonstrations are essential to the development and deployment of technologies for carbon capture and sequestration, a technology essential to the future of coal, and of enhanced "hot rocks" geothermal, one of the more promising technologies now at the prototype/demonstration stage. These technologies will require multiple demonstrations, carrying price tags upward of nine figures.

A third gap concerns the financing of investments in improved manufacturing technology and processes and energy efficiency, especially investments in manufacturing cost-cutting and production scale-up, including conservation and efficiency technology.

Underlying these three gaps is a fourth, the need to encourage and facilitate technological collaboration between government and industry across the board, and specifically in collaborative technology-roadmapping exercises.

The first of the gaps we identified has now been filled, at least in principle, by the establishment and funding of the Advanced Research Projects Agency-Energy (ARPA-E), authorized in the America Competes Act in the fall of 2007 and funded at $400 million in the American Recovery and Reinvestment Act passed by Congress and signed by the president in February 2009. The details of the institutional design of an ARPA-E are critical to its effectiveness, and these are now under review and implementation inside the Department of Energy, with a core staff in place and an initial $150 million grant solicitation issued.

To bridge the second and third gaps, we recommend the establishment of a government corporation able to recruit private-sector engineering and financing expertise capable of operating outside the limits of government procurement systems. The corporation would be able to finance demonstrations of engineering-intensive technologies as well as accelerated manufacturing scale-up of promising technologies and investments in conservation technology. Energy legislation pending in the House and Senate proposes comparable financing institutions.

To bridge the fourth gap, we recommend a roadmapping exercise, led by private industry in collaboration with the government and academic experts, that looks at each technology element and its possible and preferred evolution pathways. It would then tie each pathway to the right elements of a menu of support for research, development, and demonstration, combined with mechanisms for government support for implementation and deployment, as well as demand-oriented policies providing incentives or regulatory standards to encourage or require adoption. Because we lack even an energy technology strategy at this time, such a strategy should be a first priority, with a roadmap to evolve from it.

International implications

Global warming, energy security, and economic competitiveness are inextricably linked, which greatly complicates any purely national effort to stimulate innovation in energy technology. Both global warming and energy security are inherently international problems, to which national solutions can at best offer partial answers. What is more, both issues raise tricky questions of ethics and international relations. Although China recently surpassed the United States to become the world's leading emitter of carbon dioxide, it will be many decades before the aggregate carbon contribution of China, India, and the rest of the developing world to the atmosphere catches up with that of the presently industrialized economies. It is difficult for the United States to lecture the Chinese peasant or Indian oxcart driver on the virtues of energy conservation from the seat of its metaphorical SUV. Research collaboration raises somewhat analogous issues. U.S., European, and Japanese companies rightfully see innovation as a source of future market competitiveness, but so do Chinese and Indian firms, which are making major investments in research and manufacturing capacity. On the other hand, it is important to the future of the planet that developing countries, especially India and China, adopt sustainable energy technologies as quickly as possible.

Because of the historic strength of its innovation system, the United States will probably be needed to play a significant role in energy innovation if global progress is to be made in coming decades. However, there should be an international dimension to collaboration on innovation. The key is to maintain a sound balance between commercialization and collaboration, with commercial competition prevailing unless there is market failure or delay, in which case government can play a role. We will need to enlist capitalism in the energy cause and need to be careful to pursue policies that encourage competitive firms to enter this field. However, basic and precompetitive R&D present particular collaboration opportunities, and bi- and multilateral collaborations may offer participating nations expanded innovation resources and opportunities for market entry they would not have on their own. The Pew Center on Global Climate Change and the Asia Society Center on U.S.-China Relations have issued a joint report proposing the following priority areas for U.S.-China collaboration on energy and climate change: deploying low-emission coal technologies, improving energy efficiency and conservation, developing an advanced electrical grid, promoting renewable energy, quantifying carbon emissions, and financing low-carbon technologies.

There is a strong case to be made for international collaboration at the technology implementation stage, particularly for developing nations. The World Bank's Clean Development Fund, where developed nations support implementation in developing nations, will support this stage. Another partial answer could be linkage mechanisms in cap-and-trade systems whereby greenhouse gas reductions implemented outside a nation's borders can be credited in its national cap-and-trade compliance system. If structured properly, this could not only promote the most economically efficient investments but also offer leverage to encourage a global effort incorporating developing nations.

This cooperative approach will need to be complemented by frank and constructive dialogue concerning the many perverse national subsidies and other policies, however politically entrenched, that contribute to environmentally and economically unsustainable energy production and use in virtually every country. Technical discussions along these lines should complement the even more politically charged international negotiations over emissions targets that now constitute a major feature of international environmental diplomacy. In the end, however, in a competitive and expanding global economy and in an economic sector as vast as energy, there should be market enough for all to share.

From principle to practice

The new integrated framework that we propose has implications beyond policy theory; it also leads to a different logic for the practical design of technology policy legislation. Compared to our framework, the current U.S. legislative process for energy technology innovation is exactly backward. Today's preferred strategy, as reflected in the 2005 and 2007 energy bills, is to create legislation for each technology separately and to provide a different incentive structure for each. We argue that the incentive structure should be legislated first in such a way as to preserve the fundamental technology neutrality needed in this complex technology area.

Where complex technology sectors such as energy are involved, Congress needs to legislate standard packages of incentives and support across common technology launch areas, so that some technology neutrality is preserved and the optimal emerging technology has a chance to prevail. Particular technologies can then qualify for these packages based on their launch requirements. It is important to get away from the current legislative approach of unique policy designs for each technology, which is often based on the legislative clout behind that particular technology rather than the critical attributes of the technology itself.

The implications of our proposed approach are large, and the politics needed to implement it will not be easy, especially given the full plate of issues confronting the nation's political leaders and institutions. Huge sums of money will be involved, and the dangers of the pork barrel will be serious. It will not be simple to keep energy technology innovation efforts apart from disruptive political tampering. As with so many other issues facing the nation, presidential and congressional leadership, combined with grassroots support, will be required for this to work. As Machiavelli observed in 1513, "There is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things."

Nevertheless, it may be easier to gain political support for spending money on research and innovation, as the Obama administration's energy stimulus package suggests, than for imposing increased costs on energy and CO_2 emissions at the levels required. Accelerating the supply side of energy innovation, as efforts to impose a cap-and-trade regime are deliberated and gradually implemented, will be critical because technology supply will assure industry, consumers, and markets that putting a price on energy demand will work and be affordable. There is little time to lose.

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