Stimulating Energy Technology Innovation*

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Abstract: The innovation system has interrelated components of invention, translation, adoption, and diffusion. Energy technology innovation has lagged that in other domains, and there is a compelling public interest in picking up the pace through appropriate government action. Government and universities are creating new approaches in the invention and translation stages. The Department of Energy (DOE) has implemented novel programs such as ARPA-E. Research universities have moved closer to the marketplace through more diversified industry collaboration models, such as convening research-sponsoring companies both horizontally in a sector and vertically across the innovation chain. Much more needs to be done to expand public-private partnerships and to define a broadly accepted government role in the adoption and diffusion stages. An administration-wide Quadrennial Energy Review process, informed by technical analysis and social science research, offers the best opportunity in this regard.

The U.S. economy was the engine for twentieth-century global development. The key role of R&D in driving productivity growth has been documented extensively, and American serial innovation was instrumental in producing not just improved products but new technology-based industries. The world's preeminent research university system, a magnet for attracting top talent globally, proved central to these developments. A recent study[1] of the entrepreneurial impact of MIT alone found more than twenty-five thousand alumni-founded companies generating $2 trillion in sales and more than three million jobs worldwide. The local effect is strong, with Massachusetts-based firms producing more than $150 billion in sales and nearly a million jobs worldwide.

Societal features such as a mobile workforce and acceptance of business and investment risk support a culture of innovation. Natural advantages, including a continental scale, an immense natural resource base, the world's third largest population, and the biggest market for new products and services, are also important for U.S. performance. Together, all

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of these factors facilitate the capture of invention for domestic economic activity and for building an export base.

While this U.S. model remains strong, its very success is changing the game in an age of globalization. Many countries have invested heavily in their research universities, stemming the loss of scientific and engineering talent to other nations and encouraging start-up companies. Further, the fastest-growing markets are in the large emerging economies, which attract not only manufacturing but also global industry R&D. With the largest markets for new energy infrastructure located outside the United States, concerns about the competitiveness of the American economy over time have elevated the importance of retaining an innovation edge.

This brings us to the *innovation system*. My discussion draws on the report of the President's Council of Advisors on Science and Technology (PCAST), *Accelerating the Pace of Change in Energy Technologies through an Integrated Federal Energy Policy*,[2] which adapts a description put forward by Edward Rubin.[3] The report views the development and use of energy technologies as an integrated system, comprised of four interrelated components:

- *Invention*: discovery, creation of knowledge, and generation of prototypes;
- *Translation*: creation of a commercial product or process;
- *Adoption*: deployment and initial use of a new technology; and
- *Diffusion*: increasing adoption and use of a technology.

Importantly, these components cannot be viewed as a linear progression; multiple feedbacks occur all along the chain. That is, while invention is certainly driven by R&D, it is also propelled by the experiences that accompany commercialization, use, and diffusion. Similarly, translation emerges from R&D and may be revisited following adoption. Adoption and diffusion are the stages at which materiality of products and processes are realized (or not). *Innovation, as I use it here, refers to the end-to-end system including market diffusion, not front-end R&D alone.*

Today, clean energy is considered a key area for innovation. The reasons for this view include an anticipated doubling of global energy use and tripling of electricity demand by mid-century, and the attendant major build-out of energy supply, delivery, and use infrastructure. The drivers include economic growth in the developing world, continuing concerns about energy security, and the need to mitigate the risks of climate change. Addressing climate change, in particular, will call for a major transformation of the current fossil fuel–based energy system and inspires a vision of trillion-dollar markets for the leaders in clean-energy technology.

Yet *energy technology was largely passed by in the last decades of innovation* relative to areas such as information and communications technology and biotechnology. Jeff Immelt, the CEO of GE, has observed that during his career with the company, medical technologies have turned over several times while core energy technologies are easily recognized as improved versions of product lines from a quarter-century ago. There was, and is, a great deal of clean-energy activity at the stages of invention and translation to commercial products, often driven by an enhanced participation by venture capital firms. The level of activity at these stages reached unprecedented heights in recent years, boosted somewhat by the stimulus packages put in place in the United States and elsewhere. There have been substantial product improvements to core technologies (for example, increased efficiency of energy supply and end-use technology), but the scale-up of novel technologies across the entire innovation chain, from invention to diffusion with large market share, is modest. Arguably, wind turbines and biofuels are counter-examples; but these technologies have required substantial subsidies and/or mandates to reach their current levels of penetration, raising questions about their further scalability in the marketplace absent a societal willingness to foot a growing bill and/or pricing of externalities such as carbon emissions.

What is it about the energy system that slows innovation? Multiple characteristics should be kept in mind to address this question:

- multitrillion-dollar annual revenues;
- often, large capital needs to reach even the demonstration phase;
- a commodity business, with attendant cost sensitivity;
- well-established efficient supply chains, delivery infrastructure, and customer bases;
- provision of essential services for all activities;
- an emphasis on reliability over innovation;
- a high degree of regulation; and
- complex policy and politics, often driven by regional considerations.

None of these characteristics provides a nimble platform for end-to-end innovation. Rather, they suggest *a business with high barriers to displacement of incumbents*.

Several of the points require elaboration. Energy can be characterized as a *commodity business* in the sense that even novel technologies generally provide the same services as incumbent ones, such as producing electricity (for example, photovoltaics and coal plants) or providing mobility from point A to point B (for example, biofuels and gasoline). Consequently, rather than create novel consumer services, as numerous communication/information technologies have done, *new energy technologies inherently must displace incumbent market share*. This fact diminishes the opportunity for market entry of disruptive technologies unless they meet stringent cost tests early in their deployment. As a result, early adoption of energy technology is highly sensitive to policies and subsidies that help create the initial market.

Conversely, cost reduction must be a principal criterion for new energy technologies, lowering the barriers to new policy introduction. In particular, making zero-carbon technologies more cost competitive would facilitate acceptance of strong policies to limit greenhouse gas emissions. State utility commissions are generally required to provide lowest-cost options for consumers. Alternatively, the technologies may need to address multiple objectives to enhance political palatability. In the case of zero carbon, technologies addressing climate risk mitigation will also strengthen energy security by limiting dependence on fossil fuels, especially oil. However, these considerations generally apply to national policy rather than at the state level, where many energy technology deployment decisions are made.

An exception to the rule is the rapid scale-up of shale gas production in the United States, resulting from the introduction of hydraulic fracturing combined with horizontal drilling. Production has grown remarkably from a very small share of natural gas supply to about one-quarter, propelling the United States back into the global lead for annual natural gas production and driving down domestic prices dramatically. The shale gas "revolution" is the biggest story for U.S. energy in a long time. However, this is a case where incumbent hydrocarbon producers scaled up a business in which they already dominate the supply chains and have the processing and delivery infrastructure. These producers decide on which assets to produce as they have done for decades. It is true that intermediate-sized companies played a central role in scaling the technology before the supermajors, but significant capital availability allowed the latter to move easily into the business.

For new substitutional energy technologies, it remains to be seen how effectively the entrepreneurial culture of the start-up world can scale when incumbent energy producers are not familiar with the technology or with the risk-taking paradigm. "Impedance matching" is needed between risk acceptance (such as venture capital) and capital availability (such as equity investors and large energy companies) and between novel product development at start-ups and management attention and profit-loss reward systems at incumbents.

Another part of the shale gas story frames the innovation challenge.[4] The technology demonstration for unconventional natural gas production (coalbed methane, tight gas, shale gas) was advanced through public-private partnership and diffusion through well-timed synergistic tax incentives. A surcharge on interstate gas transportation, approved and administered by the Federal Energy Regulatory Commission (FERC), and industry cost-sharing funded the Gas Research Institute (GRI). Further, the GRI Board of Directors was required to be composed of industry representatives, from well to burner tip, plus a small number to represent the public interest. The industry thus provided both input to define the research, development, and demonstration (RD&D) portfolio around specific industry challenges and the cost-sharing needed to implement projects. Within the GRI portfolio, a major success was that of unconventional gas, driven by board members representing independent producers.

Equally important, Congress passed time-limited tax incentives for unconventional gas production during the GRI technology demonstration period. The combination of technology development and deployment incentive proved synergistic in establishing an unconventional natural gas industry that is flourishing beyond expiration of the tax credits and producing substantial revenue for the economy and the government. (I shall return to this model of government participation with the private sector in order to advance energy innovation.) Unfortunately, the energy surcharge RD&D financing mechanism that supported the GRI was phased out as a consequence of deregulation.

Highlighting the business challenges to energy technology innovation is not meant to suggest an inability to succeed, but rather to draw attention to the factors that must be addressed to accelerate innovation, which is in the public interest for many reasons. Most of all, climate-change risks grow inexorably with continuing greenhouse gas emissions, and the opportunities to mitigate the consequences of and to adapt to climate change diminish with time and become more difficult to address. In addition, the global markets for clean-energy technology are forming rapidly, and early innovation enhances the probability of capturing market share. Finally, the enormous outflow of funds for imported oil and the vulnerabilities associated with almost complete dependence on oil for transportation fuel places a premium on progress with advanced vehicles and alternative fuels. The question is, what is being done and what more can be done?

The government will necessarily play an important role if clean-energy innovation is to *be accelerated* relative to the pace of the marketplace left to its own devices. The energy system has historically required a multidecade timescale for appreciable change, which is inadequate for the purposes noted above. To accelerate the process, the government, including both the administration and Congress, has at least three distinct roles. One critical, and uncontested, function is to provide the general conditions that stimulate, or at least do not impede, innovation. A clear example is providing a framework for intellectual property (IP) protection that reaches a balance between incentivizing invention and investment without tying up intellectual capital that could stimulate further innovation. Another critical example is passage of the Bayh-Dole Act and its amendments in the 1980s, which allowed universities to move government-sponsored research outcomes to commercialization and profoundly influenced industry-university relations. In a similar vein, the National Technology Transfer Act and the National Cooperative Research Act opened up national lab-industry and industry-industry collaboration, respectively.

A second role is stimulation of technology development and support for the underlying science that enables development. Public support for RD&D is the principal mechanism. R&D financing is generally viewed as an essential government role because the results of early-stage basic research are seldom captured by a single firm, but demonstration is less widely endorsed, both on principle and because of some visible failures over the years. Support for demonstration projects can involve direct funding, such as government cost-sharing, or indirect assistance, such as a long-term purchase agreement for a product.

A third role for government, and the most controversial, is "technology pull" at the adoption and diffusion stages of the innovation cycle. In this function, the government helps create markets using a wide variety of instruments, such as portfolio standards, feed-in tariffs, investment tax credits, consumer rebates, efficiency standards, and federal long-term purchase agreements, among many others. Sometimes multiple instruments are used simultaneously for a particular technology. Viewed optimistically, the large number of approaches has evolved in order to provide options fit to purpose; less optimistically, it may reflect the lack of general support for "picking winners," instances of unintended consequences, and a mixed track record.

Recent government engagement in energy-technology invention and translation has had a positive impact on the early stages of the innovation chain. First, *the Department of Energy (DOE) has introduced three new programs that show great promise for more effectively applying public funds to fill the innovation pipeline*: Energy Frontier Research Centers (EFRCs); ARPA-E (the Advanced Research Projects Agency-Energy); and energy innovation hubs. The EFRC program, originating in the DOE Office of Basic Energy Science, was established through an exemplary process organized over several years to identify the basic science barriers to a host of energy technology breakthroughs. Engaging a wide community of scientists in a series of workshops, the program moved the Office of Basic Energy Science research portfolio more into Pasteur's Quadrant[5] of use-inspired science – an approach fitting to the DOE's mission. Each EFRC is funded at several million dollars per year and focuses on one of the many enabling-science challenges identified in the workshops. As with all these new programs (awards were first distributed in 2009), it is too early to judge outcomes; but the approach deserves praise and should be continued aggressively, at least until the first centers are evaluated on their core mission of opening new technology pathways.

ARPA-E has had the most visibility among the new programs. Established in the 2007 America COMPETES Act, it was initially funded only in early 2009 as part of the economic stimulus bill. The program aims to fund high-risk, high-reward technology development that can then qualify for venture funding within a few years. Many of the awards support university-industry collaborations, and both EFRC and ARPA-E awards generally cluster around major research universities. This highlights the central role of research universities and university-industry partnering in the innovation system, including translation of research into venture investment opportunities for commercial products.

The initial ARPA-E solicitation received well over three thousand concept papers for what was eventually narrowed to just thirty-seven awards. This 1 percent success rate is suggestive of not only an innovative program design but also an enormous capacity at American universities and other research organizations to fill the innovation pipeline. ARPA-E has supported nearly two hundred projects in little more than two years. The program design includes a staff assembled with some relatively young individuals who have experience in the venture world and serve limited terms in the program.

ARPA-E represents a very different way of doing business relative to the established applied-energy programs at the DOE. It has assembled an interesting portfolio targeted at breakthrough technology cost performance. Many of the ARPA-E operational features should be adapted to the applied programs, including streamlined procedures for contract negotiations and colocation of support functions, such as procurement, with program officers.[6] More ambitious reorganization is also necessary. The applied energy offices are organized around fuel: that is, Fossil Energy, Nuclear Energy, and Efficiency and Renewables. For one, grouping Efficiency and Renewables into one office is a relic with little logic to support it. Further, the organization of the offices is backward looking, reflecting a time when the energy marketplace and technology breakthrough opportunities were quite different. Low-carbon technologies are not focused on resource extraction (with the exception of unconventional natural gas as a bridge to a very low-carbon future[7]). The energy marketplace of the future is likely to call for new business models in areas such as electrification of the transportation sector (the lead priority in the recent DOE Quadrennial Technology Review[8]) or the integration of subsurface activity with electricity generation through carbon dioxide capture for storage and enhanced oil recovery.

A complete reorganization of the applied energy offices around key end uses, rather than inputs, would profoundly affect and improve how the RD&D portfolio is shaped. For example, in the last few years of the Clinton administration, the DOE began to utilize a cross-cutting portfolio/road-mapping approach to setting new directions. By organizing programs around strategic objectives rather than fuel, the energy offices identified and addressed major program gaps within a few years. This included both enabling science and technology (a modeling/simulation focus for energy) and applied energy needs that did not fit within the existing stovepipes (electricity grid technologies and reliability). Such an organizational change, combined with use of ARPA-E management approaches, would undoubtedly be disruptive for the applied energy offices and the companies that have become accustomed to doing business with them. Nevertheless, it would likely help these offices become much more effective components of the innovation system. Moreover, while consultation with Congress is essential, much of the reorganization could be accomplished with existing executive authorities.[9]

The third new program element is the energy innovation hub. Three have been established to date, with two more anticipated in 2012. The concept centers on large, multidisciplinary, integrated teams assembled for a multiyear effort, funded at about $25 million per year, and organized to address the basic research and applied engineering needed for a priority technology challenge. In this sense, they could be compared to a "mini-Manhattan Project." Each hub partners with industry to translate its work to commercialization. For example, the first hub was established in May 2010 to develop new predictive simulation tools that can be used by light water reactor (LWR) vendors, researchers, and regulators alike. Based at Oak Ridge National Laboratory (in partnership with the Idaho, Los Alamos, and Sandia Laboratories), it builds on a historic strength of the national labs (advancing the frontier of modeling/simulation of complex engineered systems, such as nuclear weapons), with strong university (MIT, Michigan, North Carolina State), industry (Westinghouse), and user (Tennessee Valley Authority, Electric Power Research Institute) core members. The DOE has adhered to the philosophy of an outcome-oriented oversight approach and a light touch compared to the more intrusive approach that has too often characterized program management in the applied energy offices. The hub has already developed and released an innovative software tool to simulate a virtual LWR.

The organization of the hubs is true to the core mission of the national laboratories but, regrettably, does not reflect how the DOE has in fact interacted with the labs for quite some time. *The DOE should return to a model in which the national laboratories are assigned major mission-aligned challenges that call for significant multidisciplinary teams and sustained efforts that would be difficult to carry out elsewhere.* A focus on outcomes should replace department micromanagement; management authority and responsibility should be left with the operating contractor. Despite their considerable capabilities, the national labs have "punched below their weight" in advancing energy-technology innovation, and "hubification" of the energy R&D program could greatly amplify the effective use of the labs' considerable capabilities.

All told, these new ways of doing business at the DOE are positive initiatives that show sufficient promise to warrant displacement of the management and organizational approaches of the last few decades. They are much better matched to the innovation challenges at hand and the evolving energy marketplace.

Another issue is the scale of the DOE's RD&D program. A number of recent reports, including the PCAST report and one released by American business leaders,[10] have argued for tripling the DOE's RD&D budget to about $15 billion per year. The funding level is somewhat notional, though PCAST provided a crude estimate of the scale: roughly the contribution of energy expenditures to GDP (about 9 percent in the United States) multiplied by the benchmark for public spending on RD&D (1 percent). Among the major economies, only Japan reaches this level of investment.

This budget recommendation raises at least two questions: where is the money, and how should its expenditure be organized? A sustained increment of $10 billion per year for energy RD&D is highly unlikely to occur at a time of budget tightening, and accelerating the pace of innovation calls for making these funds available sooner rather than later. Even if congressionally appropriated funds were available, a better approach might be *generating the revenue through a small charge on energy supply, delivery, and/or use* – a "return to the future" analogous to the surcharge that funded the GRI. A 0.1¢/kWh charge on electricity and a 2¢ per gallon charge on transportation fuel are well within standard variations in consumer price, and each would generate about $4 billion annually. However, while the GRI surcharge was implemented through regulation, the amount of deregulation that has since occurred suggests the need for a statutory approach.

Implementation would follow the general principles used in the GRI model: management by one or more nonprofit organizations fit to purpose; "light touch" oversight by the federal government (the DOE, in this case); a strong industry role in setting the portfolio for technology translation, adoption, and diffusion stages; and a degree of industry cost-sharing. The $5 billion DOE budget should be maintained and reweighted toward R&D, for which it has a much better track record and capability than with demonstration and deployment. The lessons learned with the EFRCs, ARPA-E, and innovation hubs would guide the expanded early-stage portfolio. An explicit mechanism should be set up as an interface between the DOE program and the public-private partnership organizations that manage the additional funds generated by the energy innovation surcharge. This provision would align management of different parts of the innovation portfolio with expertise and knowledge of both the research enterprise and the energy marketplace.

Today, *more than twenty states support efficiency programs and/or research through utility surcharges.*[11] This is just one example of the many ways in which states can take the lead on clean-energy technology and policy, setting a precedent for the federal government to follow. Energy needs and opportunities in the United States are highly variable by region, and the states are naturally more in tune with the best pathways to economic development and job creation for their particular circumstances. At least some of the nonprofit organizations charged with managing the energy innovation surcharge would be best established at the regional level, with coordination to share best practices and different implementation mechanisms that can be experimented within a regional context.

Over the last few decades, universities have moved closer to the marketplace. As noted above, conditions established through legislation such as the Bayh-Dole Act led to dramatic expansion of university-industry cooperation, a domain that previously engaged very few universities at a meaningful scale (MIT and Stanford University were prominent exceptions). Today, novel approaches are being tested at numerous institutions. For example, the MIT Energy Initiative (MITEI)[12] is collaborating with fifteen major companies as research partners. The core of the relationship is a dedicated sponsored research portfolio with customary IP terms, such as IP ownership by the university, a sponsor nonexclusive royalty-free license, and a time-limited sponsor option for a royalty-bearing exclusive license. In practice, sponsors may find ways to exploit project IP using methods other than acquiring licenses: for example, by becoming an equity investor in a start-up when the technology is adjacent to current core business. Certainly, all work is publishable after appropriate steps are taken to manage the IP.

The MITEI partnership includes a number of additional elements. Significantly, the initial five-year commitment stipulates a consultation mechanism that allows the portfolio to evolve in alignment with faculty interests and company strategic planning. Extensive exchange between university and company researchers is common. Indeed, companies with the largest portfolios place a senior research manager at the university to stay engaged with projects, maintain the back-and-forth flow of information, and identify new university researchers and opportunities.

MITEI's most interesting feature may be a set of *mechanisms that allow all the companies to come together in a commons*. The Initiative has formed a governing board that helps guide overall MITEI directions. A jointly supported seed fund provides crucial support for early-stage ideas generated by faculty across the full spectrum of energy-related activity, including, specifically, social science and management research as well as science, engineering, architecture, and planning. The companies, which span the oil, equipment, and infrastructure sectors, have seen nearly three hundred proposals over four years. Once the proposals are distributed and evaluated throughout the companies, all the companies in the partnership come together with MITEI leadership to perform an intensive selection review; this is not unlike a panel review that one might see at the National Science Foundation (NSF) or the National Institutes of Health. The discussion itself, drawing on the different interests and outlooks of companies across the energy space, is instructive. The companies have no IP capture from the funded projects but can track the projects and support extensions as part of their individual sponsored research portfolios. More than eighty such projects have been funded, and the program has served the important purpose of stimulating both new collaborative ideas with the companies and drawing in faculty who had not previously engaged in energy-related research.

As company representatives get to know one another, they begin to form small "consortia of the willing." Typically, these are cross-cutting analytical projects useful to an industry sector, although some consortia now support science and engineering with IP implications. This is one manifestation of the role of the *university as a convening place for companies, even direct competitors in the marketplace*. Another is the conferences and symposia in which the companies participate along with others in the innovation chain, such as venture capitalists and energy law firms. In other words, a space is provided for convening energy-system players both horizontally in a specific sector (for example, petroleum) and vertically along the entire innovation chain, from inventors to the largest energy incumbents.

The MITEI example highlights the growing intimacy of the university-industry relationship. This phenomenon is driven by the university commitment to engage with the marketplace (in some sense, reweighting the research portfolio to emphasize Pasteur's Quadrant rather than Bohr's[13]) and the increasing trend in industry toward open innovation models. This convergence augurs well for stimulating early-stage innovation.

Another recent development at MIT has been a series of multidisciplinary analytical studies of key clean-energy pathways that provide a sound engineering-economic base as a platform for policy recommendations grounded in facts. MIT's interdisciplinary study on *The Future of Natural Gas*, cited above, is an example. These studies do not fit the mold of traditional academic research aimed at peer-reviewed journals, although they do produce priority research agendas and graduate student theses that lead to such publication. The work requires close collaboration between natural scientists, engineers, and social scientists, particularly economists and political scientists engaged in public attitudes research. Universities have much to offer in providing policy-motivated technical analysis. Such policy, which includes that for publicly supported RD&D, can in turn have significant consequences for shaping the government role in the innovation system.

As recommended in the PCAST report, the *DOE should incorporate a multidisciplinary social science research program into its energy programs as an important component of the innovation system*. Social science research will help inform the pathway for clean-energy technologies through the entire innovation chain, exploring questions such as: How and why do such technologies satisfy consumer choice? What are barriers to adoption? How can public policy best enable technology push and pull? What economic and cultural factors may influence take-up of new technologies internationally? Would reengineering of American products help their export potential? How can start-up companies and the largest incumbents in the energy sector interface their different cultures and resources to stimulate innovation effectively? These are some of the many questions relevant to innovation that are amenable to rigorous social science research. In addition to providing sufficient in-house capacity to guide its research program, the DOE, perhaps in cooperation with the NSF, should support such research at universities and nongovernmental research organizations. An institution analogous to the National Bureau of Economic Research (or possibly even a supplement to it) would provide an interesting model.

While there are many promising new approaches to filling the energy-technology innovation pipeline at the invention and translation stages, *acceleration in the adoption and diffusion stages continues to be more challenging, especially with respect to the government role*. The public-private model discussed above can be an important contributor, especially at the adoption stage, but the prospect of implementing an energy innovation surcharge in the near future is bleak. A recent congressional initiative to introduce a "line charge" on coal-generated electricity – the proceeds of which would have established carbon capture and sequestration to enable continued coal use – did not get very far, even though the measure had a fair degree of support in the industry.

The most obvious and conceptually simple approach to accelerate low-carbon deployment at scale is the imposition of a substantial economy-wide price on carbon dioxide emissions. Alternatively, a regulatory cap on emissions that tightens over time could be put in place. In either approach, a high degree of confidence that the policy will stay in place over a considerable period of time – rather than be subject to dramatic shifts in Congress and the administration – will be important for generating private investments at scale in a timely fashion. Similar mechanisms could address the externality of energy security and oil dependence. The prospects for carbon pricing continue to be inauspicious. At best, a continuation of proxy policies such as renewable portfolio standards and tax credits, often at the state level, can be anticipated. These policies tend to be inefficient for the overarching purpose of stringent carbon dioxide emissions reductions and, by observation, have too often been subject to starts and stops. Such policy realities highlight the importance of clean-energy technology cost reduction as a more assured path to deployment and, then, to appropriate policy by lowering implementation costs. Furthermore, it is not clear that pricing externalities would accelerate innovation at the needed pace without additional energy-technology policy steps.

It should come as no surprise that I do not have the answers for how the government should intersect the latter stages of the innovation process in a general sense. However, PCAST recommended a pragmatic approach to an integrated federal energy policy that would employ all the tools available to the government in a coherent way. Termed the Quadrennial Energy Review (QER), the process is necessarily complex, but history suggests that anything short of a full multiagency effort is unlikely to provide a robust plan that accounts for the many threads of an energy policy. Furthermore, a degree of analysis is required that has not been present in previous efforts.

Energy policy is derivative of many policies: environment, technology and competitiveness, diplomacy and security, natural resources, and land and food, among many others. Indeed, multiple agencies that are not labeled "energy" have major equities and long-held perspectives on key elements of energy policy. Often, the preferred policies for different agencies' agendas conflict. Further, states and local governments play a strong role, for example with building codes, and their approaches can vary dramatically in different parts of the country; certainly, California's energy policies have influenced the national market. The tools available to support innovation are also diverse, ranging from direct support of RD&D to a variety of economic incentives, regulation, standards, and federal procurement, among other instruments. Congress is equally fragmented: in the House of Representatives and Senate, many committees beyond those tasked with energy policy have equities that mirror those of the different executive agencies. To overcome this fragmentation of responsibilities and perspectives, and especially if the goal is a plan that has staying power in advancing adoption and diffusion, PCAST recommended a

> QER process to provide a multiyear roadmap that:
>
> - lays out an integrated view of short-, intermediate-, and long-term objectives for Federal energy policy in the context of economic, environmental, and security priorities;
> - outlines legislative proposals to Congress;
> - puts forward anticipated Executive actions (programmatic, regulatory, fiscal, and so on) coordinated across multiple agencies;
> - identifies resource requirements for the RD&D programs and for innovation incentive programs; and, most important,
> - provides a strong analytical base.[14]

This is a tall order intellectually and organizationally. Several process elements are essential to fostering a chance for success. First, the Executive Office of the President (EOP) must use its convening power to ensure effective cooperation among the myriad relevant agencies. However, the capacity to carry out such an exercise and to sustain it does not (and should not) reside in the EOP. The DOE is the logical home for a substantial Executive Secretariat supporting the EOP interagency process that would present decision recommendations to the president. However, the scope of the analytical capability needed does not currently reside at the DOE or any other agency. The DOE needs to build this capability, presumably supplemented by contractor support to gather data, develop and run models, and carry out analysis, such as independent energy-system engineering and economic analysis. Market trends and prices would be part of the analysis, including international markets and robust analyses of uncertainty. The Energy Information Administration can help with some data gathering and models, but its independence from the policy function needs to be preserved. The national laboratories also lack this range of functions, and tasking them with providing the analytical support to the policy process would be regarded as a conflict of interest; their focus is best directed at research, invention, and technology transfer. Building this analysis capacity is a large job that will take time.

For the QER to succeed, the government must seek substantial input from many quarters in a transparent way; certainly, ongoing dialogue with Congress and the energy industry are essential. The good news is that members of Congress have supported the development of the QER[15] as a way to present a coherent starting point for congressional action across many committees. A hope is that *Congress could then use the QER as a basis for a four- or five-year authorization that would provide the private sector with the increased confidence needed to make sound clean energy investment decisions*.

Given the magnitude of the task, PCAST recommended in 2011 that the DOE carry out a Quadrennial Technology Review (QTR) – a first step centered in a single department and focused on technology. The QTR resulted in a rebalancing of the R&D portfolio toward the oil dependence challenge through advanced vehicle development, particularly transportation electrification. The key now will be to extend the processes developed for the QTR to the multiagency QER, involving the EOP in a leadership role. Taking the next steps in 2012 will maintain momentum and establish the capabilities needed for the QER by early 2015, the time frame recommended by PCAST.

While some may view 2015 as a frustratingly long time away, the alternative is to rely on wishes rather than analysis while failing to gain multiple perspectives in a fair and open manner. Rushing the process will result in a poorly done job that will not accomplish any of the key QER goals. Certainly, it will not bring together succeeding administrations and Congresses around a reasonably shared vision and set of objectives that can accelerate innovation in service of national competitiveness and environmental and security goals. Continuing with fragmented and economically inefficient policies, technologies "du jour," and frequent shifts will complicate private-sector decisions rather than facilitate innovation. The government unavoidably plays a strong role in the innovation process, even when this is unacknowledged in policy and political debates. The issue now is to present both a set of principles and fact-based analyses supporting coordinated government-wide actions that earn decent buy-in from major stakeholders.

ENDNOTES

[1] Edward B. Roberts and Charles Eesley, *Entrepreneurial Impact: The Role of MIT* (Kansas City, Mo.: Kauffman Foundation, 2009).

[2] President's Council of Advisors on Science and Technology (PCAST), *Report to the President on Accelerating the Pace of Change in Energy Technologies through an Integrated Federal Energy Policy* (Washington, D.C.: Executive Office of the President, November 2010), http://www.whitehouse.gov/ostp/pcast.

[3] Edward S. Rubin, "The Government Role in Technology Innovation: Lessons for the Climate Change Policy Agenda," *Proceedings of the 10th Biennial Conference on Transportation Energy and Environmental Policy*, Pacific Grove, California, 2005.

[4] *The Future of Natural Gas: An Interdisciplinary MIT Study* (Cambridge, Mass.: Massachusetts Institute of Technology, 2011).

[5] Donald Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation* (Washington, D.C.: Brookings Institution Press, 1997).

[6] PCAST, *Accelerating the Pace of Change in Energy Technologies*.

[7] *The Future of Natural Gas*.

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