SCIENCE, TECHNOLOGY, AND PUBLIC POLICY PROGRAM

INSTITUTIONS FOR ENERGY INNOVATION:

A TRANSFORMATIONAL CHALLENGE

VENKATESH NARAYANAMURTI, LAURA D. ANADON, AND AMBUJ D. SAGAR

Fall 2009

BELFER CENTER
for Science and International Affairs
John F. Kennedy School of Government
Harvard University

ACKNOWLEDGMENTS

The authors are grateful to the Climate Change Initiative of the Doris Duke Charitable Foundation for supporting the work of the Energy Research, Development, Demonstration, and Deployment (ERD3) Policy Project and the Science Technology and Public Policy Program, both at the Belfer Center of Science and International Affairs of the Harvard Kennedy School.

All responsibility for any errors or misjudgments rests solely with the authors.

CITATION INFORMATION

This paper may be cited as: Narayanamurti, Venkatesh, Laura D. Anadon, and Ambuj D. Sagar, *Institutions for Energy Innovation: A Transformational Challenge*. Cambridge, Mass.: Report from the Science, Technology and Public Policy Program, Belfer Center for Science and International Affairs, Harvard Kennedy School, Fall, 2009. Comments are welcome and may be directed to Venkatesh Narayanamurti, Laura D. Anadon, and Ambuj D. Sagar at the Belfer Center, Kennedy School of Government, Harvard University, 79 JFK Street, Cambridge, MA 02138.

ABOUT THE AUTHORS

Venkatesh “Venky” Narayanamurti (venky@seas.harvard.edu) is the Benjamin Peirce Professor of Technology and Public Policy and Professor of Physics at Harvard University. He is also the director of the Science, Technology, and Public Policy Program of the Harvard Kennedy School of Government.

Laura D. Anadon (laura_diaz_anadon@harvard.edu) is the manager of the Energy Research, Development, Demonstration, and Deployment Policy Project at the Harvard Kennedy School of Government.

Ambuj D. Sagar (asagar@seas.harvard.edu) is Vipula and Mahesh Chaturvedi Professor of Policy Studies at the Department of Humanities and Social Sciences of the Indian Institute of Technology Delhi and Visiting (faculty) Scholar of the Science Technology and Public Policy Program at the Harvard Kennedy School of Government.

Cover Image: Kathleen Stynes removes the cover from the heat transfer tube on the prototype SkyTrough on South Table Mountain (STM) overlooking NREL's Golden, CO campus. The SkyTrough was developed by SkyFuel, an Alburquerque-based manufacturer with a research facility near NREL in Arvada, CO. The unit's lightweight glass-free mirrors are made of sheet metal beneath ReflecTech© mirror film. This highly-reflective, silver-metalized film is lighter and less expensive than the breakable glass mirrors that are traditionally used. The film is a joint invention of NREL and ReflecTechT and exclusively licensed from NREL.
Source: Courtesy of DOE/NREL, Credit - Pat Corkery

Institutions for Energy Innovation: A Transformational Challenge

Venkatesh Narayanamurti, Laura D. Anadon, and Ambuj D. Sagar

The United States must change the way it produces and uses energy by shifting away from its dependence on imported oil and coal-fired electricity and by increasing the efficiency with which energy is extracted/captured, converted, and utilized if it is to meet the urgent challenges facing the energy system, of which climate change and energy security are the most pressing. This will require the improvement of current technologies, and the development of new transformative ones, particularly if the transition to a new energy paradigm is going to be timely and cost-effective.

The Obama administration and the Secretary of Energy understand that the *status quo* will not deliver the results that are needed and have significantly increased funding for energy research, development, demonstration, and deployment and are putting in place new institutional structures. But policymakers must also pay much more attention to improving the management and coordination of the public energy technology innovation enterprise. For too long a focus on design and management elements necessary to allow government-funded innovation institutions to work effectively has largely been absent in policy debates—although not from many analysts minds and reports.

The nation is, in fact, at a historical point where the nation's energy innovation system is being examined, significantly expanded, and reshaped. As the country does this, it not only has a rare opportunity, but indeed a responsibility, to ensure that it improves the efficiency and effectiveness of this system to make sure that the country is getting the maximum payoff from its investments. In this context, the importance of improving and better aligning the management and structure of existing and new energy innovation institutions to enhance the coordination, integration, and overall performance of the federal energy-technology innovation effort (from basic research to deployment) cannot be over-emphasized. The technology-led transformation of the U.S. energy system that the administration is seeking is unlikely to succeed without a transformation of energy innovation institutions and of the way in which policymakers think about their design. With this article we wanted to present our principles as a starting point of a much-needed conversation among analysts, managers, scientists, and policy-makers on how to enhance the effectiveness of these institutions.

Drawing lessons from successful efforts by some large U.S. private-sector research institutions and by the national laboratories we highlight five particular elements that we believe are key to effective management of the energy innovation institutions: mission, leadership, culture, structure, and management, and funding. All of these elements must be healthy and in balance with one another to ensure the robustness of the innovation ecosystem.

Furthermore, the external political and policy environment within which these institutions are embedded, and the evolving nature of innovation also determine their effectiveness and, therefore, managing outside intervention, coordinating with broader policies and regulations, and adapting to the dynamic nature of the innovation should be seen as an integral part of the challenge.

Apparently aware of the inadequacy of the structure and management of the current federal energy technology innovation effort, the administration has promoted several initiatives such as the Energy Frontier Research Centers (EFRCs) to support larger research teams working in coordination and the Energy Innovation Hubs to better integrate the innovation steps from research to commercialization as was done by Bell Labs. It has also supported the creation of ARPA-E to try to replicate the success of the Defense Advanced Projects Research Agency (DARPA). Other experts have proposed additional strategies. In *Issues*, Ogden, Deutch, and Podesta proposed the creation of an Energy Technology Corporation to select and execute large-scale demonstration projects, and a panel assembled by the Brookings Institution recommended the creation of a national network of a few dozen Energy Discovery-Innovation Institutes to address the failure that "most federal energy research is conducted within 'siloed' labs that are too far removed from the marketplace and too focused on their existing portfolios to support 'transformational' or 'use-inspired' research targeted at new energy technologies and processes."

We highlight five particular elements key to effective management of energy innovation institutions: Mission, Leadership, Culture, Structure and Management, and Funding.

The S&T community welcomes decisive government action, but the management and coordination of new and old initiatives and institutions is indeed a very difficult and complex task, and it is one that is not receiving enough attention from policymakers. The Energy Innovation Hubs, for example, could—if they adhere to the principles we describe—fulfill an important gap in the U.S. innovation system by better integrating basic and applied science in a mission-driven approach. The design of ARPA-E has incorporated some of these principles from its inception, particularly the independence of the leadership. Its success will be determined in part by the extent to which the other principles are applied in practice.

The technology innovation process is complex and nonlinear, complex because it involves a range of actors and factors and nonlinear because technology innovation occurs through multiple dynamic feedbacks between the stages of the process. Furthermore, the technology innovation system is made up of many institutions, including universities, large firms, start-ups, the federal government, states, and other international and extra-national institutions, and the relationships (or linkages) between them.

The complexity of the innovation process is especially great for energy technologies for a number of reasons:

- There are limited and uncertain market signals for energy research, development, and demonstration (RD&D) and for deployment. The externalities of greenhouse gas emissions and energy security, for instance, are not appropriately represented in the market, and thus there is widespread belief that the RD&D and deployment that takes place is not commensurate with the challenges facing the energy sector and the technical opportunities that are available.
- The large scale of many energy technologies such as clean-coal processes and nuclear power and the long timeframes over which their development takes place further hinder the participation of the private sector in the development of such technologies.
- Energy technologies are very heterogeneous within each stage—research, development, demonstration, early deployment, and widespread diffusion—offering different challenges, with early deployment and subsequent expansion issues being particularly important.
- Energy technologies ultimately have to compete in the market place with powerful incumbent technologies and integrate into a larger technological system, where network and infrastructure effects may lead to technology "lock-in."

The public-goods nature of energy technologies thus necessitates a multifarious role for the government: ensuring the availability of future technology options, reducing risk, developing more appropriate market signals, and often even helping create markets. As a result, the federal government is not only a major funder and performer of energy RD&D but also a major player in facilitating the introduction of technologies into the market. Given the particularly large scale and scope of the energy area, the design and management of energy innovation institutions and their interactions with the rest of the energy system is extraordinarily complex.

Working out the specific details for each of the energy innovation activities will require further effort but the literature on the design and management of innovation institutions and personal experiences of managers does offer some key interconnected principles for the success of the new—and reshaping of old—public institutions and initiatives for enhancing U.S. energy technology innovation.

GUIDING PRINCIPLES

The public sector effort must be pluralistic, reflecting the range of activities and needs relating to the energy sector. For example, in technology areas where the venture capital community or other private sector entities are active in pursuing the commercialization of technologies and the barriers to demonstration and deployment are lower, it may make more sense to emphasize the university research/spin-off model. In technology areas where infrastructure and networks are essential, public-private partnerships may play a key role. And in many cases, centralized R&D facilities, modeled on large corporate laboratories that focus on long-term research but are informed by real-world needs, may be the most appropriate.

Managing Large Innovation Efforts: Lessons from the History of Corporate Laboratories

The institutions and programs with the task of catalyzing the change should learn the right lessons from the history of managing large corporate innovation efforts. Examples of large corporate industrial laboratories that have been involved in cutting-edge invention and commercialization include Bell Labs, IBM research, and Xerox PARC.

The case of the AT&T and Western Electric's Bell Labs is particularly interesting because, as a large, vertically-integrated, regulated utility, the long-term focus on technological innovation was unexpected. Before Theodore Vail took over as AT&T's CEO in 1907, AT&T's strategy to reach the goal of hegemonizing the national telephone service involved acquiring outside patents, focusing on perfecting engineering systems—rather than to engage in applied science and create inventions—and rapidly extending wire coverage (which threatened its financial position). During his first years Vail vigorously promulgated inside and outside the company a new company ideology that focused on technical achievement and began changing the Bell Systems' innovation enterprise, culture, and structure. This change was in part driven by AT&T's desire to achieve long-distance telephony, and in part from its need to protect itself from a potentially disruptive new technology, radio. Louis Galambos detailed in 1992 that a few years after becoming AT&T's CEO, Vail expressed his conception of the AT&T innovation system as "an ever-living organism" and laid out the foundation of systems engineering; in Vail's view innovations had to be "co-ordinated and carried on in connection with the practical operation over ... [the entire] system ...". Vail infused the entire organization with a remarkable blending of adaptive and formative innovation efforts.

Vail knew that for the new strategy to be sustainable, it had to be embodied in the firm's structure. He also ensured that there was a direct line of communication between the research effort and the firm's direction. Thus, he centralized research and development operations and brought them closer to manufacturing, which would contribute to blending basic and applied research. By standardizing license contracts with Bell operating companies (who paid 4.5% of gross revenue to AT&T for the System's central administration), Vail obtained a relatively secure source of funding for research. Finally, Vail appointed technically oriented officers to positions of authority. Vail's legacy paved the foundation of the Bell Labs in 1925.

Bell Labs achieved a seamless integration between basic and applied research; communication between researchers and product developers also allowed for the translation of key inventions into products, from electronic repeaters, to UNIX operating systems, to electronic switching. Furthermore, its record in recruiting and retaining excellent scientist and engineers was unparalleled. In addition to Theodore Vail's legacy, research managers, like Mervin Kelly, who became Director of Research at Bell Labs in 1936, had a large role in maintaining a culture of excellence, integrating between disciplines and research groups, and foreseeing the potential applications of innovations and the role of applied science. Prominent among its list of illustrious achievements, Bell Labs researchers developed the transistor, which transformed computers, lasers, and solar cells.

Xerox PARC provides a different example where the value of remarkable stream of inventions by researchers was not fully captured by the corporation, although most of the ideas successfully found their way into application through spin-offs. This, of course, offers an alternative, although inadvertent from the point of view of the parent institution, pathway to innovation. Like Mervin Kelly in the Bell Labs, George Pake, who was in charge of creating the Xerox PARC research organization, succeeded in recruiting the world's best researchers in the field.

The concept of "open innovation" illustrates the dynamic nature of the innovation system. Pioneered by Berkeley's Henry William Chesbrough, this model of innovation assumes that useful knowledge is widely distributed and that "even the most capable R&D organizations must identify, connect to, and leverage external knowledge sources." Chesbrough and his colleagues argue that ideas that were once generated only in large corporate laboratories now grow in settings from the individual inventor, to start-ups, to academic institutions, to spin-offs, and they claim that at least some high tech industries, the open-innovation model has "achieved a certain degree of face validity."

Although we recognize the heterogeneity of energy systems and the ever-changing nature of the relevant innovation enterprise, on the basis of our personal experience and the history of the corporate and national labs, we maintain that it is still possible to identify five elements that are essential to create and run a successful technology innovation institution. These elements are: having a clearly defined mission; attracting visionary and technically excellent leaders; cultivating an entrepreneurial and competitive culture; setting up a structure and management system that balances independence and accountability; and ensuring stable predictable funding. We believe that they provide a good framework for restructuring current institutions and designing and evaluating proposals, once a functional gap in the system has been identified.

A CLEARLY-DEFINED MISSION THAT IS INFORMED BY, AND LINKED TO, A LARGER SYSTEMS PERSPECTIVE.

As is clear from the examples of some large corporate labs, for example Bell Labs, Xerox PARC and IBM, mission, leadership, culture, and funding are important to create a productive innovative environment. Several examples of successful large U.S. government-driven efforts, such as the Manhattan Project and the Apollo Project, highlight particularly well the importance of having a clearly-defined mission.

A well-defined mission facilitates attracting top employees, enables reaching an institution's objectives more effectively, and significantly to the overall integration and coordination of the energy innovation system. The inspiration provided by an exciting mission has often been the most forceful magnet for attracting the best people and for research at the frontier. And clarity on the mission facilitates the design of an appropriate organizational structure for the institution.

The technological underpinnings of an innovation institution should be adaptive and flexible enough to reflect the needs, information, and context of the times. The telecommunications sector, for instance, provides an excellent example of research efforts that are able to adapt quickly to incorporate new technologies, satisfy new demands, and comply with new regulations.

Finally, the mission of the publicly-funded innovation institutions should typically focus on providing a public good and/or tackling a market failure. Whenever possible, the licensing or technology transfer practices of these entities should aim to create an industry rather than a product.

LEADERSHIP THAT HAS PROVEN SCIENTIFIC AND MANAGERIAL EXCELLENCE, HAS A VISION OF THE ROLE OF THE INSTITUTION OR ENTERPRISE IN THE OVERALL ENERGY SYSTEM, AND IS CAPABLE OF ACTING AS AN INTEGRATOR OF PROCESSES.

An institution or initiative charged with an innovation mandate must have a visionary leader with excellent managerial <u>and</u> scientific/technical credentials. The additional complexities of the energy system require leaders to also have an exceptional understanding of the role of his or her institution in the overall system and an ability to integrate the different activities within and outside the institution.

As with the mission, leadership should not only have a systems perspective, but also be adaptive and cognizant of the dynamic nature of markets and the innovation system. Leaders must recognize change and manage and structure their organization accordingly.

A leader with strong people-management skills can create an environment where people know the boundaries but are able to flourish. In other words, people must not feel actively managed; they must have freedom but without losing focus. As we will discuss shortly, leaders can also promote this "insulate but not isolate" management approach through different levels of the organization by fostering the right culture and putting in place the right structure.

Fortunately, President Obama has chosen Department of Energy leaders whose experience prepares them for the holistic thinking required to manage energy innovation institutions, and this needs to be propagated throughout the energy innovation institutions.

ENTREPRENEURIAL CULTURE THAT PROMOTES COMPETITION BUT ALSO COLLABORATION AND INTERACTION AMONG RESEARCHERS.

Cultivating the right culture is often forgotten in discussions about the management of government enterprises. But one cannot overstate the importance of having a culture of excellence that pervades the entire organization from the top to the bottom. A culture of technical excellence helps drive a virtuous circle in which the best will be attracted to the important research in energy technology innovation partly because that is what the best are working on.

Researchers and managers should operate in an entrepreneurial environment that encourages personal initiative and creativity and the search for new ways of solving problems. This environment should be characterized by openness and healthy competition and a culture for attacking the most pressing and challenging problems. The principle of "insulate but not isolate" is also useful in describing the balance to which these entities should aspire. Researchers must have independence to test and experiment, and at the same time be accountable for their efforts. In other words, they must have freedom to explore new paths, while keeping in mind, and being motivated by, the long-term questions.

Exploration of multiple approaches should be welcome and encouraged, especially during the early stages of research. Using several approaches, in particular for high-priority projects, increases the chances of overcoming problems and finding a more optimal solution, and may reduce product development times. However, the value of pursuing multiple approaches will be realized only with the right culture of collaboration as well as entrepreneurship.

MANAGEMENT PROCEDURES AND ORGANIZATIONAL STRUCTURES THAT PROMOTE INDEPENDENCE, AND YET GIVE PRIMACY TO PERFORMANCE AND ACCOUNTABILITY.

Structurally, it is important that the management does all it can to break down the all-too-common separation between basic and applied research and among disciplines. The greater the integration between those doing basic and applied research, the faster technologies will incorporate relevant new fundamental knowledge about processes and materials. As former IBM executive Lewis Branscomb has discussed, corporate laboratories such as the T.J. Watson Research Laboratories of IBM do not attempt to distinguish between basic and applied research; their work is simply referred to as "research." Energy-innovation institutions must also eliminate this divide.

The independence of directors and managers at different levels of the organization and the creation of a critical mass of researchers for each undertaking will also be essential to make progress at the speed required by the energy-related challenges. Research directors and managers must have a high level of independence to adjust their actions at their discretion by allocating resources and people according to new information as it becomes available, while focusing on the long-term mission of the organization. At the same time, the director of the innovation institution needs to have regular access to the Secretary of Energy for strategic reasons and to ensure the nimbleness of the organization to circumvent bureaucratic barriers.

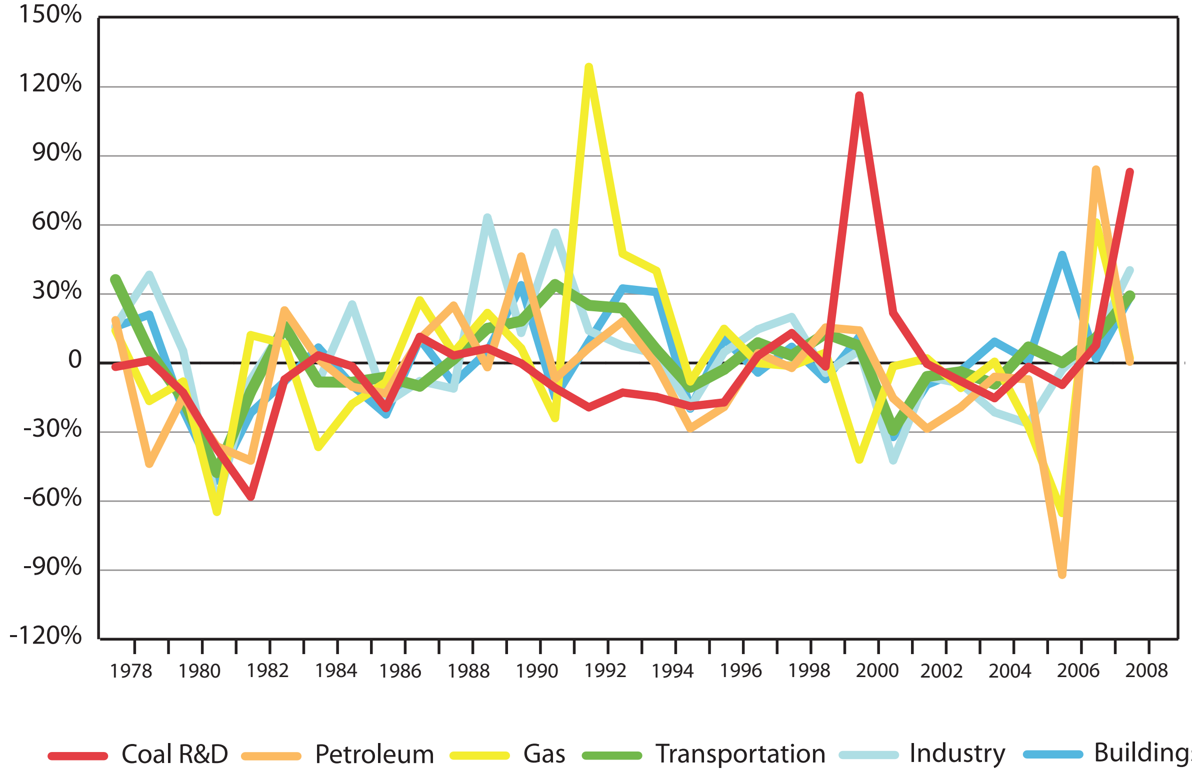
Researchers must have independence to test and experiment, and at the same time be accountable for their efforts.

A critical mass of researchers is essential to combine sufficient expertise and points of view to arrive quickly at the best possible outcomes. Intellectual competition with exploration of multiple pathways is critical for success; thus the structure and the culture of the organization are tightly interrelated.

Recruitment of the best talent is a key to success in innovation and requires the attention of top management. This sends a signal of the importance of recruiting and allows those with a deep technical knowledge and breadth of vision to bring on board the appropriate kind of talent for the long-term direction of the organization.

The management of energy technology innovation institutions should also expend significant effort in developing a cadre of technically-skilled managers who can nurture creative scientists, inventors, and problem-solvers and have the capacity and knowledge to carry out meaningful performance reviews of personnel and programs. This ensures that those entering the institution are acculturated appropriately, that there will be a pipeline of trained managers for the continuity of the culture of excellence, and that researchers and managers will continue to bring value to the organization by avoiding knowledge stagnation.

Figure 1: Year-to-year variation in RD&D funding from the Department of Energy for six fossil energy and energy efficiency technology areas from 1978 to 2008



STABLE AND PREDICTABLE FUNDING THAT ALLOWS A THOROUGH AND SUSTAINED EXPLORATION OF TECHNICAL OPPORTUNITIES AND SYSTEM-INTEGRATION QUESTIONS.

Stable, sufficient, and predictable funding is another important requirement for a successful energy innovation institution. R&D projects tend to need several years (although the specific timescale may vary from area to area) before a decision can be made about whether to move forward. R&D managers need to have certainty that funds will be available to meet their goals and to produce enough information to enable managers or directors to make decisions about the future of each project. Block funding at each appropriate management level is important.

The annual appropriation process, at least in the form it has taken in recent years, is not suitable to appropriately support research in energy innovation. The year-to-year percentage change in funding over time for fossil energy, energy efficiency, and renewable energy at the Department of Energy serves to illustrate the point about stability. Figure 1 shows the year-to-year DOE funding variation for six fossil energy and energy efficiency research areas from 1978 until 2009. The average standard deviation of the variation across these six programs was 27%. This means that on average every year there was a one in three chance that these programs would receive a funding change (increase or decrease) greater than

A Case of Government-Supported Innovation Institutions: The National Laboratories and Their Evolution

The original design and management of the U.S. national laboratories contained most of the elements we have described: a clear mission, stellar leadership, an entrepreneurial culture, block funding, and a government-owned contractor-operated (GOCO) structure that was compatible with the "insulate but not isolate" principle. As a result, the innovation record of the labs was impressive, especially in the early years.

The renowned Manhattan Project, which produced the first nuclear weapon in two years, successfully integrated the work of what today we know as the Los Alamos, Argonne, Oak Ridge, and Sandia GOCO labs. Although the experience of managing research in this and other defense- and space-related programs cannot be directly translated to tackle the technologies that need to compete in the marketplace, it is important to understand how the mission and management of the national labs has changed over time and how that has affected their innovative capacity. Although this is an area that deserves further study, our preliminary analysis suggests that:

- With time, the mission of the multiprogram national labs has become more diffuse. The lack of alignment between their new missions and their structure affects the ability of some of the labs to achieve their full innovative potential.
- In some cases, the important focus on operational requirements such as safety and security has been pursued at the cost of a decreasing primacy of the technical mission.
- Funding for the basic energy sciences program has often occurred through small grants to individual investigators, which is a great model for university research but not an effective way to integrate basic and applied science. In addition, funding for many of the applied science DOE programs has been very volatile.

The interplay of these factors, combined with the difficulty of securing block-funding for nondefense projects, has disrupted the delicate innovation system required to achieve the labs' full potential. It has become almost impossible to implement the insulate but isolate principle, because even though the GOCO system is still in place, the political climate has changed so that in practice the labs are no longer insulated from the government bureaucracy and have evolved to a management that is akin to that in civil service institutions. As a result, their innovative and entrepreneurial culture as well as their independence have been significantly compromised. In addition, the multiplicity of missions now assigned to each lab makes it impossible for any individual to play the effective integrator role that Robert Oppenheimer filled during the Manhattan project.

The national labs have tremendous talent and capabilities to advance energy innovation but will only be able to fulfill their potential to advance energy innovation if they are freed from the internal and external barriers to improved management.

27%. The gas program had the largest standard deviation of the year-to-year funding variation (36%), whereas the vehicle technologies program had the lowest standard deviation (18%). Figure 2 illustrates the large year-to-year variation for five renewable energy areas from 1992 to 2008.

Figure 2: Year-to-year variation in RD&D funding from the Department of Energy for five renewable energy–technology areas from 1992 to 2008

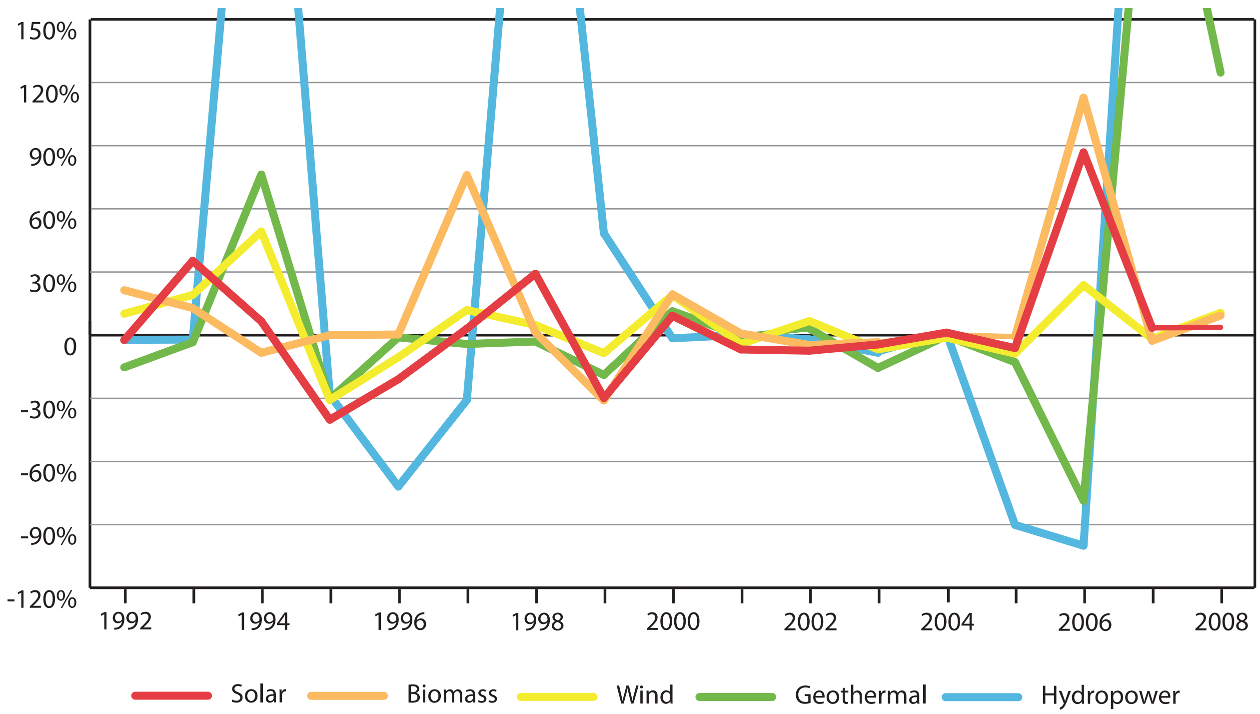


Figure Notes:
No information is available before 1992 for the funding areas above. The 2007 value of the 'hydropower' series is not computable since the 2007 funding was zero.

Although some changes in overall funding amounts from year to year are expected, the high volatility of the DOE budget reflects department-wide rapid change priorities and directions. Any good strategy should be flexible enough to be adjusted and improved with time as more information becomes available, but the changes in DOE's funding reflect the difficulty in securing block amounts of funding for specific purposes over time. Funding should have second level, as opposed to first level, fluctuation constants, by which we mean that after setting a general direction (which may be revised when new analysis and information is available) funding changes should not disrupt a program's main operations, although minor adjustments may be allowed. Block funding enables research managers to make rapid adjustments within their programs over a couple of years without having to go back to Congress. As with research performance, decisions about funding should be subject to review. The need for performance reviews and funding stability are intricately linked, because without one, the other one will not work.

A Fractal View of Managing Innovation Institutions?

There are certain features for the management of innovation institutions that are important at every scale: from the individual researcher, to a research group, to divisions, and the overall institution. In some sense, these features could be thought of as fractal characteristics, i.e., present different scales of analysis. We are not aware of any literature discussing fractal properties of innovation institutions, and clearly validating and exploring this potential framework will require future research; but we believe that a fractal framework may provide, in principle, a useful tool to understand some aspects of managing innovation.

» **Insulate but not isolate**: The first example of an element important at every scale (from researchers, to managers, to the institution) is the need to insulate from micro-management (or even interference by external environment such as the political and the budget processes), while making sure that the view of the bigger picture or the institutional mission are not lost. The role of leaders and managers as system integrators is critical here by ensuring a delicate coupling on the substantive side while buffering against administrative perturbations.

» **Independence but review**: The second example of a fractal characteristic that we have aimed to highlight is the need to allow independence of action, and yet subject individuals (researchers and managers), units, and institutions to regular performance reviews. The particular characteristics of the reviews and the actions allowed by the independence will differ across levels, but the combination of freedom and accountability should help ensure that creativity and excellence pervade the organization.

» **Funding at appropriate scale**: Each institution, its departments, and even researchers must be provided funding at appropriate scales—in terms of both magnitude as well as timeframe—so as to explore technical opportunities in a manner commensurate with the area.

» **Focus on people**: The success of any organization depends on the people within, but this is particularly relevant for innovation institutions. While the relevant characteristics of personnel may change depending on their level and role, the importance of technical ability remains constant—technical excellence is as important for managers and leaders as for researchers. Recruiting (and retaining) the right people at all levels is key.

THE OUTSIDE WORLD

In addition to the internal factors essential for an institution to successfully perform or fund energy innovation, there are other factors external to the institutions that policymakers should heed.

The first is the need for independence from outside interference, which in the case of public agencies includes the political process. Bureaucratic interference should be minimized because it often collides with the five elements discussed above. The notion of "insulate but not isolate" is as true for institutions, as it is for research groups and individual researchers.

The coupling of research and funding institutions to the external environment has to be delicate. Although their priorities and programs obviously have to be governed by and respond to societal needs, they should not be shaped by political exigencies or issues that are the "flavor of the month." Like researchers and R&D managers, the innovation institutions themselves need independence, tempered by accountability.

The second main external factor that innovation institutions should manage is the evolving nature of innovation. As Chesbrough and his colleagues have argued, networks and linkages are becoming increasingly important because in some sectors knowledge is widely dispersed across of variety settings from garages to national labs. Institutions must be designed to function within the overall system and to evolve with it. They should incorporate an understanding of the role of the private sector, regulators, and consumers as well as an openness to a certain degree of coupling with these other actors.

To conclude, the much-needed technology-led transformation of the U.S. energy system is unlikely without a transformation of its public energy innovation institutions. In order to be effective, the internal design of these energy-innovation institutions has to be given careful thought, with particular attention to the five elements mentioned above to nurture research and couple it to application. But the best functioning institution can become ineffective in the absence of an appropriate external political and bureaucratic environment and appropriate linkages with other actors. Therefore, just as an energy innovation institution is itself a delicate ecosystem, it should also be seen as part of a larger ecosystem, with the understanding that the effectiveness of the overall innovation system depends on the functioning of the components of the system, the relationships among them, and a connection to the broader environment in which it is embedded.

RECOMMENDED READING

L.D. Anadon and J.P. Holdren. "Policy for Energy-Technology Innovation." In: K.S. Gallagher, ed, *Acting in Time on Energy Policy* (2009). Washington D.C., United States: Brookings Press.

L.M. Branscomb. "From Science Policy to Research Policy." In: L.M. Branscomb and J.H. Keller, eds, *Investing in Innovation: Creating a Research and Innovation Policy that Works* (1998). Cambridge, MA, United States: MIT Press.

H. Chesbrough. "Graceful Exits and Missed Opportunities: Xerox's Management of its Technology Spin-off Organizations." *Business History Review,* 76 Winter (2002):803-837.

H. Chesbrough, W. Vanhaverbeke, and J. West, eds. *Open Innovation: Researching a New Paradigm* (2006). Oxford, United Kingdom: Oxford University Press.

L. Galambos. "Theodore N. Vail and the Role of Innovation in the Modern Bell System". *Business History Review,* 66 No. 1 (1992):95-126.

K.S. Gallagher and L.D. Anadon. "DOE Budget Authority for Energy Research, Development, and Demonstration Database." *John F. Kennedy School of Government, Harvard University* (2009). [Available at: http://belfercenter.ksg.harvard.edu/publication/19119/].

K.S. Gallagher, J.P. Holdren, and A.D. Sagar. "Energy-Technology Innovation." *Annual Review of Environmental Resources,* 31(2006):193-237.

A. Grübler. *Technology and Global Change* (1998). Cambridge, United Kingdom: Cambridge University Press.

J.P. Holdren and A.D. Sagar. "Assessing the Global Energy Innovation System: Some Key Issues." *Energy Policy*, 30 No.6 (2002):465-469.

S.J. Kline and N. Rosenberg, eds. *An overview of innovation. In The Positive Sum Strategy: Harnessing Technology for Economic Growth* (1986). Washington D.C., United States: National Academy Press.

B. Lundvall, ed. *National Innovation Systems: Towards a Theory of Innovation and Interactive Learning* (1992). London, United Kingdom: Pinter.

P. Ogden, J. Podesta, and J. Deutch. "A New Strategy to Spur Energy Innovation." *Issues in Science and Technology,* Winter (2008).

L.S. Reich. "Industrial Research and the Pursuit of Corporate Security: The Early Years of Bell Labs." *Business History Review,* 54 No. 4 (1980):504-529.

ABOUT THE SCIENCE, TECHNOLOGY, AND PUBLIC POLICY PROGRAM

Science, Technology, and Public Policy Program
The science and technology (S&T) enterprise plays an increasingly central, often essential, role in almost every aspect of our life. It is therefore critical to understand how we may be able to best realize the potential of S&T in improving the human condition, underpinning economic and social development, supporting human endeavors, and in promoting international relations. At the same time, we must also be cognizant of, and address, the societal concerns that often result from advances in S&T.

Public policy plays a critical role in mediating this interface between S&T and society: it should aim to enhance the positive contribution of S&T to society while recognizing, even anticipating, and mitigating, its adverse consequences.

Accordingly, the Science, Technology, and Public Policy Program (STPP) at the Belfer Center for Science and International Affairs engages in research, teaching, and outreach on how:

- science and technology influence public policy;
- public policy influences the evolution of science and technology;
- the outcomes of these interactions affect well-being in the United States and worldwide; and
- the processes involved can be made more effective and their outcomes more beneficial (at present and in the future).

Please visit our website:
http://belfercenter.ksg.harvard.edu/project/44/science_technology_and_public_policy.html

Please contact us by e-mail at **stpp@hks.harvard.edu**.

Science, Technology and Public Policy Program
Belfer Center for Science and International Affairs
Harvard Kennedy School of Government
Harvard University
79 John F. Kennedy Street, Mailbox 53
Cambridge, MA 02138