REPORT TO THE PRESIDENT ON ACCELERATING THE PACE OF CHANGE IN ENERGY TECHNOLOGIES THROUGH AN INTEGRATED FEDERAL ENERGY POLICY

Executive Office of the President

President's Council of Advisors on Science and Technology

NOVEMBER 2010

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EXECUTIVE OFFICE OF THE PRESIDENT

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

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President Barack Obama
The White House
Washington, DC 20502

Dear Mr. President,

We are pleased to send you this report, *Accelerating the Pace of Change in Energy Technologies Through an Integrated Federal Energy Policy*. This report addresses one of the greatest challenges facing our country: how to transform the energy system within one to two decades, through leadership in energy technology innovation, for reasons of economic competitiveness, environment, and security.

In this report, the President's Council of Advisors on Science and Technology (PCAST) calls for the development of a coordinated government-wide Federal energy policy. This will be a major undertaking, given the large number of Federal policies that affect the development, implementation, and use of energy technologies. For that reason, we recommend that the Administration initiate a process analogous to the Quadrennial Defense Review undertaken every four years by the Department of Defense. A Quadrennial Energy Review (QER) could establish government-wide goals, coordinate actions across agencies, and identify the resources needed for the invention, translation, adoption, and diffusion of energy technologies. The development of such a policy would enhance our energy security and create jobs as well as mitigate the risk of climate change.

Our report, which was informed by the deliberations of a working group consisting of PCAST members and prominent energy experts from the public and private sectors, makes several other important recommendations. It urges a substantial increase in Federal support of energy-related research, development, demonstration, and deployment and suggests exploration of several new revenue options to provide this support. This increase will provide the U.S. with the potential to leapfrog over other countries also investing in the development of energy technologies. We recommend that the Secretary of Energy should prepare and implement the DOE component of the full interagency QER focused on energy technology innovation, promptly. In addition, it recommends organization and process changes that would accelerate progress toward energy innovations. Our report also contains recommendations in the areas of workforce development, social science research, use of the government's procurement capacity, and international cooperation.

Responding to the energy-related challenges of competitiveness, climate change, and security will require leadership across the energy innovation chain – from invention to diffusion – but with a dramatic acceleration relative to the half century that has been the norm to move new energy systems from initial development to thorough integration in the economy. Unleashing this innovation could be one of the most important and enduring accomplishments of your Administration.

Sincerely,

John P. Holdren
Co-Chair

Eric Lander
Co-Chair

The President's Council of Advisors on Science and Technology

Executive Summary

Accelerating the Pace of Change in Energy Technologies Through an Integrated Federal Energy Policy

A clean, secure, safe and affordable energy future is among the preeminent challenges facing the United States, and a major acceleration is needed in the pace of energy technology innovation – invention, translation, adoption, and diffusion. The U.S. must be at the forefront of energy technology innovation over the next decade for reasons of:

- **economic competitiveness:** renewal of our own energy infrastructure and access to rapidly growing global markets for clean energy technology;
- **environment:** rapid progress towards lower-carbon energy in this decade as a prudent response to global warming risks; and
- **security:** scaling-up of technologies that reduce oil dependence and thereby improve both our balance of payments and our security posture.

Meeting this challenge will require extraordinary actions at the Federal level, in concert with the private sector that owns and operates the vast majority of the energy supply, distribution, and use enterprise.

In the fall of 2009, the Secretary of Energy asked the President's Council of Advisors on Science and Technology (PCAST) to review the energy technology innovation system to identify and recommend ways to accelerate the large-scale transformation of energy production, delivery, and use to a low-carbon energy system. In response, PCAST formed a working group of PCAST members and energy experts from the public and private sectors that met twice in the first half of 2010 to address the charge and formulate recommendations. Informed by the working group's deliberations, PCAST has developed this report to provide advice to the Administration about Federal actions that can promote energy technology innovation.

Our most important recommendation is that the Administration establish a new process that can forge a more coordinated and robust Federal energy policy, a major piece of which is advancing energy innovation. Many Executive Branch agencies and departments must be engaged, with leadership from the Executive Office of the President. This is needed because "energy policy" is an amalgam, and often derivative, of policies for environment, competitiveness, security, finance, land use, and more. **The President should establish a Quadrennial Energy Review (QER) process that will provide a multiyear roadmap that lays out an integrated view of short-, intermediate-, and long-term energy**

objectives; outlines legislative proposals to Congress; puts forward anticipated Executive actions coordinated across multiple agencies; and identifies resource requirements for the development and implementation of energy technologies. The Secretary of Energy should provide the Executive Secretariat for the QER. While the QER will be a product of the Administration, substantial input from the Congress, the energy industry, academia, NGOs, and the public at large will be essential to the process. A staged process should be implemented now so as to provide some elements of a QER during each of the next four years.

We recommend that the Secretary of Energy prepare and implement a DOE-Quadrennial Energy Review, focused on energy technology innovation, as a component of the full interagency QER on a shorter timescale. The DOE-QER should include roadmaps for key energy technologies, an integrated plan for the involvement of the national laboratories in energy programs, portfolio assessments that lay out the optimal deployment of resources, identification, and projections of demonstration projects, and identification of funding needs for each technology. This QER will also be prepared with strong input from many sources inside and outside of the Administration including industry, business, state and local governments, non-governmental organizations, and consumers.

A complete and integrated QER will take longer to mature. While a good start should be made in 2011, the full government-wide QER should be targeted for delivery in early 2015. PCAST encourages Congress to use the QER as a basis for a 4-year authorization process that guides annual appropriations. The Federal investment in energy research, development, demonstration, and deployment (RDD&D) is incommensurate with the objective of leadership in energy technology innovation. **We recommend a substantial increase – to $16 billion per year – in Federal support for energy RDD&D**. Given the difficulty of increasing appropriated funds to this level and the importance of "front-loading" the required investment to jump start innovation, we recommend an alternative approach. **The President should engage the private sector and Congress so as to generate about $10 billion per year of additional RDD&D funding through new revenue streams. This increase will provide the U.S. with the potential to leapfrog to development and deployment of the advanced energy technologies that will define a robust 21st century energy system.**

In addition, the Federal Government should catalog the existing energy subsidies and incentives as a first step to realignment with QER priorities, enhance its opportunity to advance energy innovation through its purchasing power, and leverage international collaboration to advance energy technology innovation.

DOE needs to implement existing authorities over its organization, administration, and processes by extending to all DOE energy programs the review, contracting, funding, and organizational reforms implemented successfully[1] by Advanced Research Projects Agency – Energy (ARPA-E); managing demonstration projects so as to adhere to private sector practices to the maximum degree possible; working with the Office of Management and Budget and the Treasury Department to eliminate barriers to DOE's expeditious implementation of its responsibilities in such areas as loan guarantees and cost sharing; and creating separate Offices of International Affairs and of Energy Policy.

1. Although the ultimate success of the research funded by ARPA-E is unknown, it is clear, as evidenced by the three solicitations managed by ARPA-E, that they have been successful in their peer review of proposals, quick negotiation of contracts, and rapid hiring of high caliber personnel.

For workforce development, DOE should establish a new traineeship program to address critical skill areas for its energy science and technology mission. Finally, DOE should initiate, along with NSF, a multidisciplinary social science research program that will provide critical information and support for policy development that advances diffusion of innovative energy technologies.

An overview of PCAST's recommendations is provided in the box below.

OVERVIEW OF PCAST RECOMMENDATIONS
TO ACCELERATE THE PACE OF CHANGE IN ENERGY TECHNOLOGIES
THROUGH AN INTEGRATED FEDERAL ENERGY POLICY

Recommendations to Administration and Department of Energy:

2-1 Establish a full interagency Quadrennial Energy Review (QER) led by the Executive Office of the President.

2-2 Develop and implement the DOE component of the full interagency Quadrennial Energy Review promptly.

Recommendations to Administration:

3-1 Increase annual energy RDD&D funding to about $16B.

3-2 Generate $10 of the $16 billion through new revenue streams.

3-3 Realign energy subsidies and incentives.

3-4 Enhance the Federal Government's ability to advance energy technology innovation through its purchasing power.

3-5 Reestablish the Committee on International Science, Engineering, and Technology within the National Science and Technology Council.

Recommendations to Department of Energy:

4-1 Direct $12 billion of the $16 billion to Research, Development, and Demonstration (RD&D) funding, with an emphasis on DOE competitive programs.

4-2 Exercise authorities to align internal processes and organization with energy objectives.

4-3 Establish a DOE training grant program.

4-4 Initiate a multidisciplinary social science research program.

The President's Council of Advisors on Science and Technology

Report to the President on
Accelerating the Pace of Change in Energy Technologies
Through an Integrated Federal Energy Policy

Executive Report

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I. Energy Technology Innovation and the Federal Role

A clean, secure, safe and affordable energy future is clearly among the preeminent challenges facing the United States and other nations. It calls for a major acceleration in the pace of energy technology innovation: invention, translation, adoption, and diffusion. This report concerns the Federal role in fostering such accelerated innovation, while recognizing that most energy decisions are ultimately taken in the private sector. Specific actions are recommended both Administration-wide and more specifically for the Department of Energy.

Why is energy technology innovation important? The same reasons are as true today as in PCAST's 1997 report:

- Economically, according to the Energy Information Administration (EIA), expenditures on energy accounted for 8.8 percent[2] of gross economic product in the United States in 2007. Periods of excessive energy costs and cost volatility have caused economic harm to our citizens, but on the other hand, energy technology, with global sales running in the multi-hundreds of billions of dollars per year, present important economic and job opportunities.
- Environmentally, energy supply accounts for a large share of the most worrisome environmental problems – from smog and acid precipitation, to stresses on water utilization, to the build-up of greenhouse gases in the atmosphere.
- National security is linked to energy through oil dependence and the geological and geopolitical realities of oil supply, through the danger that nuclear weapons proliferation or nuclear terrorism could be aided by nuclear power developments, and through the instability that can develop in strategically important regions because of failed energy services and/or environmental degradation. The energy insecurity of allies, as with natural gas, can affect us indirectly by limiting freedom of action in foreign policy.

American economic competitiveness, environmental stewardship, and enhanced security depend on picking up the pace of energy technology innovation in this decade. Many other countries are quickening their step, and we must do so as well if we are to retain our leadership position.

The Challenge to Energy Research and Development (R&D)

New energy systems typically take a half century to move from initial development to thorough integration in the economy. And, price signals to encourage the deployment of new energy technologies have proved difficult to implement. But it is imperative to speed up the end-to-end innovation process:

- **For economic competitiveness:** Historically, the U.S. has been a technology leader in energy and in many other critical industries. This, of course, rests on the foundation of our unparalleled

2. The most recent Energy Information Administration (EIA) data are for 2007. For more information, see http://www.eia.doe.gov/emeu/aer/txt/ptb0105.html.

research and innovation enterprise. But this leadership has also been aided tremendously by our being the largest market for the new technologies. This will not be the case for energy over the coming decades, as the developing world adds energy infrastructure at a dizzying pace. We must "ride the wave" and be at the forefront of energy technology innovation over the next decade to renew our own energy infrastructure with cleaner, more efficient, and more economic technologies and to set markets abroad. The alternative will be uncharacteristically to become a "technology-taker," with the implied economic and leadership consequences.

- **For the environment:** Technology innovation, often spurred by regulation and market incentives, has dramatically cleaned up energy supply with regard to conventional pollutants. Carbon dioxide (CO_2) is now the great challenge because of its heat-trapping characteristics. The best science suggests that dramatic reductions in CO_2 emissions need to start this decade in the industrialized world, and with little delay in the emerging economies as well, to mitigate the risk of major consequences. To meet the economic tests that will be crucial for creating large global markets for low-carbon technologies, acceleration across the innovation chain – from science and invention to diffusion – is essential. The economic and security benefits of leading in low-carbon technology innovation reinforce the prudence in mitigating climate risks.
- **For security:** The oil shocks of the 1970s provided a short-lived impetus to reducing oil dependence. Thirty years later, we experienced $140/barrel oil. Today, we are "exporting" about a billion dollars per day for imported oil and face serious national security and foreign policy constraints because of the industrialized world and emerging economy dependence on oil for mobility. The complexities of the Middle East do not require elaboration. However, scientific advances over the last decades in biology, nanotechnology, and other scientific areas have opened promising technology pathways – biofuels, NG and synthetic fuels, advanced batteries, and hydrogen – that can provide elasticity in the transportation fuels market. We have the scientific tools and now need to apply them with an urgency appropriate to the national security benefits of reduced oil dependence.

These considerations set the stage for extraordinary action by the Federal government to support not only R&D on new energy technologies but also demonstration, adoption, and diffusion of these technologies in concert with the private sector.

A strengthened innovation system will almost certainly give rise to a host of "game-changers" that yield many benefits. Among those potential benefits are:

- pollution-free electricity generated by economical deep-water wind farms that mitigate siting concerns, inexpensive solar photovoltaics that enable highly distributed generation, and advanced nuclear reactors and fuel cycles that minimize waste and proliferation concerns;
- an end to oil's stranglehold on mobility through the development of advanced biofuels from waste and feedstock grown on marginal land and practical batteries that eliminate electric vehicle range anxiety; and

- new services and efficiencies enabled by leading-edge information technology, including smart grids and smart homes that deliver new consumer services and smart, collision-free urban transportation systems.

The Federal Government has many instruments that it can use to accelerate the creation and implementation of new energy technologies. These include research support, technology development, tax and other financial incentives, procurement, technology demonstration and deployment, regulation, standards development, knowledge dissemination, intellectual property protection, public-private partnerships, Federal-state coordination, support for education, immigration law, and international agreements. These instruments involve the responsibilities of many different Executive Branch agencies and Congressional committees. In the past, many actions taken by different administrations and congressional entities have been at cross-purposes with regard to their effects on energy technologies. In this report, we call for a much more integrated and coherent Federal approach to energy policy and technology innovation.

The Energy Technology Ecosystem

The vast majority of the U.S. energy supply, distribution, and use enterprise is in the private sector. That is where the decisions are taken and investments made with respect to energy technology implementation. Nevertheless, Federal and state policy plays an important role in setting rules for the marketplace, often pricing externalities such as environment and security into the market. As is appropriate for a commodity that is so essential to how society functions, energy is also a heavily regulated enterprise so as to account for various public goods – universal electricity service, reliability and safety, health and environmental protection, and the like. This report focuses on the Federal role in this much larger system.

A major component of the Federal Government's role in the energy technology ecosystem is its support for science and technology. Traditionally this support has been divided into the categories of research, development, demonstration, and deployment (RDD&D). This remains a practical way to organize Federal programs. For a discussion about accelerating technology innovation, design of these programs is best considered in a framework that more closely resembles the process by which new technologies are developed and deployed. One such formulation views the development and use of energy technologies as an integrated ecosystem with four interrelated components:

Invention: Discovery, creation of knowledge, generation of prototypes;

Translation: Creation of a commercial product or process;

Adoption: Deployment and initial use of a new technology; and

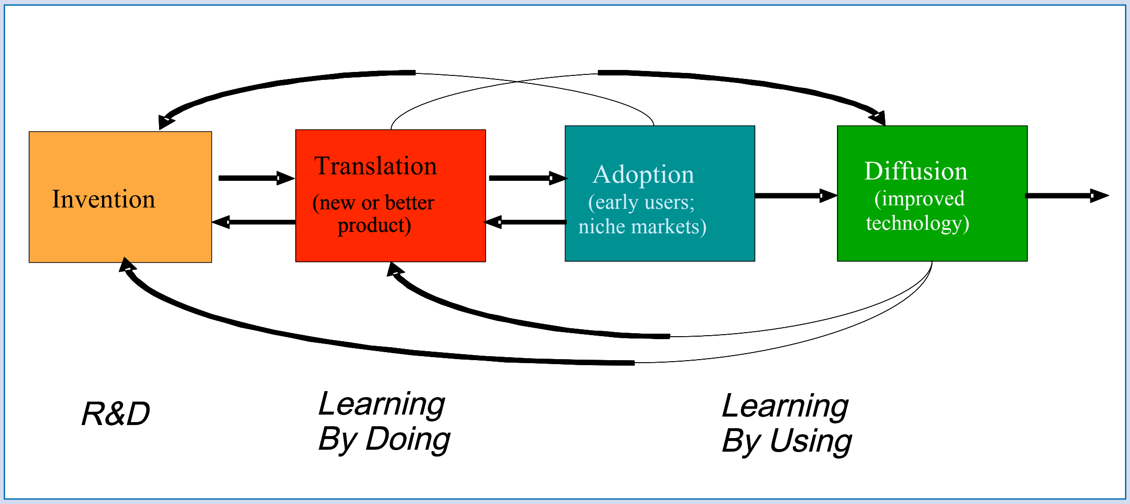
Diffusion: Increasing adoption and use of a technology.

Invention is driven in part by research and development, but it has many other sources as well. Invention also can arise through the commercialization, use, diffusion, and continued adoption of technologies.

Translation, in this formulation, refers only to the creation of a commercially offered product or process. It does not mean that a product will be adopted or become widely used.

Adoption and **diffusion** are essential for a product or process to become widely used. Those two stages are also the most critical for renewing our energy infrastructure, because of the need for new technology to displace incumbent technologies. The most serious shortfall exists at the diffusion stage because no single entity has responsibility for promoting the increasing adoption and use of a new technology. The issues go well beyond DOE's mission and involve a broad range of other government functions and factors outside government. Rather than being a simple linear process, the different stages of technological change are highly interactive, as depicted in Figure 1-1. Thus, invention and translation are critical to adoption and diffusion of new technologies because they help to improve their performance or reduce their costs.

FIGURE 1-1. PROCESS OF TECHNOLOGICAL CHANGE



The processes of technological change, adoption and diffusion typically involve a continuing series of inventions and translations that require new research and development, while adoption and diffusion continually influence invention and translation.

Source: Adapted from E.S. Rubin. (2005). *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: Toward a Policy Agenda for Climate Change. Pacific Grove, CA. Accessible at http://www.its.ucdavis.edu/events/previousevents/asilomar2005/presentations/Rubin.pdf. In this figure, the word "innovation" in the original has been replaced by "translation."

Through its support of energy science and technology – mostly through the Department of Energy – the Federal Government does a reasonable job in the invention stage of the energy technology ecosystem. But the government historically performs much less well at translation, adoption, and diffusion, partly because the Federal actions that influence these components of the energy technology ecosystem are diffused so widely across government, and partly because energy sector decision-making is ultimately in the hands of the private sector.

Origins of This Report

In the fall of 2009, the Secretary of Energy asked PCAST to review the energy innovation system, focusing on what has worked well, what has not worked well, and the barriers to change. The charge was to identify and recommend ways to accelerate the large-scale transformation of energy production, delivery, and use to a low-carbon energy system at a pace commensurate with mitigation of climate change risk (Appendix A).

In response, PCAST formed a working group of PCAST members and energy experts from the public and private sectors (Appendix B). The working group met twice during the first half of 2010 to address the charge, gather additional input from energy experts (Appendix C), and formulate recommendations. Members of the group had the opportunity to meet with Members of Congress and their staffs and with DOE and Administration officials. Several overarching questions framed these discussions, including:

1. What is the appropriate Federal role in transforming the energy sector?
2. How can that role best be implemented in the near, medium, and long terms?
3. Would a reorganized Department of Energy be more effective? If so, how should DOE be reorganized?
4. What steps can be taken within current statutory authorities?

Informed by the working group's deliberations, PCAST has developed this report to provide advice to the Administration about the Federal role in the energy technology ecosystem. While the Department of Energy is a focus of this advice, we also recognize that much of the Federal Government will be involved. The need for an integrated energy innovation policy throughout the federal government is discussed in Chapter II. Our recommendations in Chapter III address the role of the Federal Government in general, while our recommendations in Chapter IV focus specifically on the Department of Energy.

II. Toward an Integrated Energy Innovation Policy

The oil shocks of the 1970s first called attention to the need for a clear Federal energy policy, leading both to policy initiatives that drove technology development (such as vehicle fuel efficiency standards) and to organizational change – most importantly the creation of the Department of Energy (DOE). Federal support for energy RD&D increased dramatically with the establishment of DOE, but the Department was vested with only limited authority to advance and implement energy policy. The RD&D support waned dramatically with falling oil prices and fading memories of gasoline lines. Actions taken by other agencies continued to have profound impacts on the energy sector - most clearly the actions taken by the Environmental Protection Agency to limit emissions of criteria pollutants.

This very limited history serves to illustrate a key point: "energy policy" is an amalgam, and often a derivative product, of a wide range of policies directed at the environment, economic competitiveness, national security, taxes, technology, land use, and more. Significant regional differences in energy supply and demand add another dimension to the difficulty in formulating an integrated energy policy. This confluence of policies and interests has, over the years, led to a lack of clarity about what constitutes the government's energy policy. A very large number of Executive Branch departments and agencies are involved (the Departments of Energy, State, Treasury, Defense, Agriculture, Interior, Transportation, Housing and Urban Development, and Commerce, the Environmental Protection Agency, the Office of Management and Budget, the Nuclear Regulatory Commission, the Council on Environmental Quality, the Office of Science and Technology Policy, and so on), and the instruments used to implement policy are just as diverse. They go well beyond the RD&D agenda that is centered in DOE (with additional important RD&D components in agencies such as the National Science Foundation, the Department of Defense, the Department of Agriculture, and the National Institute of Standards and Technology).

In addition, multiple actors outside of the Federal government are involved. Most important, of course, is the private sector, given the way energy provides essential services for most human activities. The adoption and diffusion of energy technology at large scales reflect private decisions, although often conditioned by government policies. State and local governments also play crucial roles, most especially because of their regulatory responsibilities in support of consumers. For example, local building codes and state utility commissions are among the most important influences on the adoption of many new energy technologies. To accelerate innovation in the energy system, Federal policy must align with the needs of these stakeholders.

Furthermore, the organization of Congress mirrors the Administration's organizational challenges. While there are committees with the lead for energy issues, many of the authorities for a coherent energy policy are understandably spread across multiple committees.

Providing a Full Energy Technology Innovation Agenda

The energy technology innovation agenda should be viewed as a core element of the larger energy policy. That policy needs to set objectives across the entire innovation ecosystem – invention, translation, adoption, and diffusion – to accelerate a low-carbon transformation for purposes of both climate change risk mitigation and energy security. To achieve society's energy goals, the energy technology agenda needs to be informed by social science research. It must also utilize economic analysis to determine how best to incentivize the cost-effectiveness of the private sector.

The scope and complexity of an integrated energy and energy technology innovation policy and of aligned research programs, incentives, regulations, and partnerships ranging across the innovation ecosystem calls for interagency coordination and policy development at the level of the Executive Office of the President (EOP).

RECOMMENDATION 2-1: The President should establish a Quadrennial Energy Review (QER) process that will 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**
- **provides a strong analytical base.**

Multiple offices within the Executive Office of the President (including the Office of Energy and Climate Change Policy, the Office of Science and Technology Policy, the National Security Council, the Office of Management and Budget, the Council on Environmental Quality, the National Economic Council, the Domestic Policy Council, the Council of Economic Advisors, and others) will be engaged in this process, and the President should identify who will lead the QER.

An enterprise of this scale will need a large dedicated staff with considerable knowledge about the energy industry and energy technology and with substantial analytical capability. We recommend that the Secretary of Energy provide the QER Executive Secretariat in direct support of the EOP.

A QER process would, in some sense, formulate an integrated energy policy for the twenty-first century. It will span mission and vision definition, strategy, and tactics. The QER and the process leading to it would provide an effective tool for Administration-wide coherence on energy and for effective dialog with Congress on a coordinated legislative agenda. Presidential interest and engagement will be a necessary ingredient for success.

While the QER will be a product of the Administration, substantial input from the Congress, the energy industry, academia, state and local governments, nongovernmental organizations, and consumers will be essential throughout the process. Transparency in the process of gathering input for the QER will be key to the development of a sound product that can gain wide support.

With regard to the energy technology innovation agenda, which will be an important component of the QER, we emphasize two points that bear on how objectives are defined and programs are implemented.

First, the emphasis should be on the Federal role in establishing technology **options** for future marketplace decisions, not on specific technology deployment targets that, at large scale, are best realized by a collection of private sector economic decisions. Clearly the economics of those decisions will be shaped by externalities, such as an anticipated price or constraint on carbon dioxide emissions, and it is a critical government role to help prepare the way for those technology options that may be crucial (for example, with a carbon price). The focus on options should be reflected by technology-neutrality of the objectives. An options framework rather than one based on large-scale deployment targets has material consequences for how government programs are structured and evaluated.

Second, the QER should reflect the appropriateness of highly **differentiated** approaches to stimulating energy innovation for different technology pathways to a low-carbon future. For example, the set of government actions needed to advance nuclear power, carbon capture and sequestration, and building efficiency options are very different.

Of particular importance are the steps the government can take to help diffuse energy technologies. Existing law and regulation creates unexpected barriers when applied to diffusion of new energy technology.[3] And multiple actors are involved at all levels of government (e.g., local building codes, state regulatory commissions). The government role in diffusion is to create market conditions for widespread use of technologies needed to meet public policy goals. The essential antecedent to this role is that a significant and durable government commitment to the public policy goals exists. The tools available include:

- providing economic or regulatory incentives to encourage the use of technologies, services, and business models that meet the policy goal (e.g., appliance standards, carbon price);
- setting codes and standards based on the capabilities and attributes of the preferred technology (e.g., LEED);
- working with state and local governments to promote the use of preferred technology;
- making room for new technology (e.g., encourage the retirement or retrofitting of existing infrastructure);
- removing legal and regulatory barriers to diffusion; and
- creating conditions favorable to private sector financing.

3. Marilyn Brown and Jess Chandler. (2008). Governing Confusion: How Statutes, Fiscal Policy, and Regulations Impede Clean Energy Technologies. *Stanford Law and Policy Review,* 19: 472-509. Accessible at http://slpr.stanford.edu/previous/Volume19/BrownChandler_19slpr472.pdf.

To support the widespread adoption and use of technology, the government needs public policy goals in a QER that can motivate actions across agencies and at the highest levels. A QER can specify the obstacles to diffusion, and when appropriate use information from the social sciences to overcome those obstacles. Technology for technology's sake or invention for invention's sake will not be sufficient in the 21st century. Responsibility for setting these goals goes well beyond the reach of DOE. No mechanism exists at present for managing this cross-cutting challenge.

Initiating the Full Interagency Quadrennial Energy Review at the DOE

In the previous section, we called for a government-wide Quadrennial Energy Review (QER) that would yield a long-term comprehensive energy strategy for the Nation. DOE would serve as the Executive Secretariat for the preparation of the QER, with input and participation from other Federal agencies, other levels of government, academia, and the private sector.

The development and implementation of the government wide OER will be difficult. Since DOE is the lead agency in support of energy science and technology innovation, it is recommended that DOE should initiate the process by conducting a Quadrennial Energy Review of its own programs and policies. The experience gained will be invaluable for developing the processes and framework for the government-wide QER. The DOE component of the full interagency Quadrennial Energy Review (DOE-QER) will provide the key DOE objectives, priorities, and resource requirements. It will serve as the basis for coordination with other agencies and on other programs for which DOE has a key role. For example, it will contain concrete and measurable objectives to achieve a sustained and effective Federal energy program.

RECOMMENDATION 2-2: The Secretary of Energy should prepare and implement the DOE component of the full interagency DOE Quadrennial Energy Review on a shorter timescale than the full QER. This DOE-QER will guide DOE's role within the overall Federal effort in accelerating technological change in the energy sector.

In addition, PCAST encourages Congress to use the QER as a basis for a 4-year authorization as it does with the Department of Defense Quadrennial Defense Review. The appropriation process will continue to be annual, but a 4-year authorization provides the time needed for the actions recommended in the QER to be initiated and its outcomes to be assessed.

The preparation of the first DOE-QER should be started immediately with a completion target of June 1, 2011. This will build on the internal roadmapping processes already begun at DOE. This initial DOE-QER will provide Congress with guidance as it works on the FY 2012 budget. In successive years of this first QER four-year cycle, DOE should update the DOE-QER each January in conjuction with buildup of the government-wide QER, for which DOE serves as the Executive Secretariat. The first QER and DOE-QER covering a complete four-year period should be prepared and released by January 2015, at the start of the 114th Congress. After that, the QER and DOE-QER would be on the quadrennial schedule.

Like the QER, the DOE-QER needs strong external input from many sources, including other levels of government, large and small businesses, academia, national laboratories, Congress, nongovernmental organizations, consumers, and other Federal agencies. An advisory board consisting of representatives of these constituencies would provide a formal means of guiding the development of the DOE-QER. The newly reconstituted Secretary of Energy Advisory Board (SEAB) can play an important role.

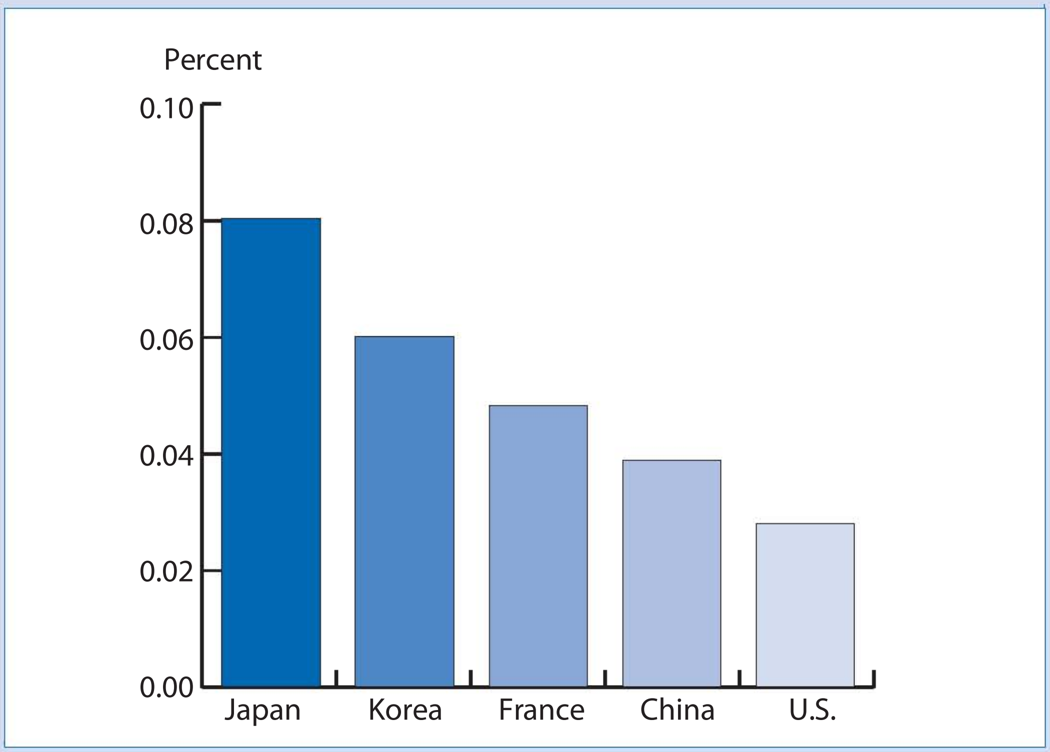
Items to include in the DOE-QER include:

- Roadmaps for key energy technologies that include performance goals, milestones, and critical decision points; projections of costs and benefits; and analyses of technical and market risks. These roadmaps should encompass both long-terms goals and short-term specific goals to be accomplished within the four-year period of the DOE-QER.
- Peer review processes to be followed in RD&D awards.
- An analysis of the needed actions of performers, including academia, industry, and national laboratories, as a function of technological area, including energy efficiency, renewable energy, electricity reliability, fossil energy, and nuclear energy. Requirements for invention, translation, adoption, and diffusion should be mapped onto each of the applied energy programs.
- An integrated plan for the involvement of the national laboratories in energy programs.
- Portfolio assessments that lay out the optimal deployment of resources, including prioritizing financial resources and the resources of the national laboratories.
- A mapping of the linkages among the Energy Frontier Research Centers, the Bioenergy Research Centers, ARPA-E, and the Energy Innovation Hubs with each other and with the applied programs, including consideration of appropriate exit strategies for any given technology or center.
- A description of the coupling between basic research and the applied programs.
- Identification and projections of demonstration projects, including time frames, milestones, sources of funding, and management.
- Identification of funding needs for each technology, with consideration of public-private partnerships and the need for funding through such mechanisms as loans and loan guarantees.
- Identify programs that can be enhanced with international cooperation.
- Identification of policy gaps that need to be filled to accelerate the adoption and diffusion of energy technologies. Some of these gaps will fall within the responsibilities of other Federal Agencies, such as initial purchases and other procurement decisions by the Department of Defense or tax credits provided through the Department of the Treasury.
- An analysis of energy markets and market failures, identification of points of maximum leverage for policy intervention to achieve outcomes, analysis of where energy policy can be most effective in driving the energy sector to meet national goals.

III. Filling the Innovation Pipeline

The scale of investment in energy RD&D has been recognized as too low for quite some time. Among industries dependent on advanced technology, energy is anomalous in that the technology R&D investment as a factor of sales revenue is less than a percent for the Federal government and large industrial firms combined, an order of magnitude below most technology-driven industries. At these levels, the U.S. cannot capture the economic competitiveness, environmental, and security advantages outlined in Chapter I. As seen in Figure 3-1, the U.S. invests substantially less in RD&D as a function of GDP than do representative set of other countries.

FIGURE 3-1. PUBLIC ENERGY RD&D SPENDING AS A SHARE OF GDP, 2007



Source: American Energy Innovation Council (2010). *A Business Plan for America's Energy Future*. Washington, DC: American Energy Innovation Council. Accessible at http://www.americanenergyinnovation.org/full-report.

A standard benchmark for overall Federal R&D funding in industrialized countries is 1 percent of GDP (and an additional 2 percent from the private sector). If energy expenditures represent 8 percent of GDP, a fairly typical level for industrialized countries (the U.S. was at 8.8 percent in 2007 according to the EIA), then 0.08 percent would be the benchmark for Federal energy R&D. Only Japan, among those listed above, reaches that level, with the U.S. a full three times below.

Still, there is no magic number for what the Federal energy R&D budget should be. PCAST called for a doubling of energy RD&D government support in 1997.[4] A group of over thirty Nobel prize winners called for a tripling last year. Brookings called for a $20-30B annual level. Most recently, the American Energy Innovation Council (AEIC), a group of American business leaders whose enterprises are rooted in technological innovation, issued *A Business Plan for America's Energy Future*.[5] The AEIC mission is "to foster strong economic growth, create jobs in new industries, and reestablish America's energy technology leadership through robust, public investment in the development of clean energy technologies." The Council recommends that the government invest $16 billion per year in clean energy innovation, roughly a tripling of current DOE investments in energy science and technology. This would be divided into $12 billion for R&D and $4 billion for large-scale demonstrations and deployment.

There are several indicators that an increase of this magnitude is justified. For example, large scale commercial demonstrations are typically billion dollar order of magnitude. For carbon capture and sequestration alone, a portfolio of demonstrations is needed. These would employ both coal and natural gas, two fossil fuels in which the U.S. is largely self-sufficient, and include power plants (e.g., gasification, oxycombustion, and other advanced concepts) and conversion plants (e.g., for fuels production). An aggressive program to demonstrate these technologies and point the way to cost reductions would take up the better part of a billion dollars per year for many years, even with industry cost-sharing. And then there are large scale demonstration needs for modular nuclear reactors, advanced concentrating solar technologies, deepwater wind, engineered geothermal systems, and others.

Detailed examination of R&D programs leads to similar conclusions about the need for expanded investment. A good example is the collection of novel programs started at DOE during this Administration: Energy Frontier Research Centers (focused on the invention stage), ARPA-E (focused on the translation stage), and Innovation Hubs (spanning the innovation chain from invention to adoption). The total funding for all three programs is about $500M/year and could easily merit $2B/year, a four times increase. This is highlighted by ARPA-E's experience of being able to fund only about one percent of the applications in the first round of competitive, peer-reviewed applications. A benchmark for highly competitive, peer-reviewed government R&D programs (NIH, NSF, etc.) would be proposal success rates in the range of 20 percent. The EFRC and Hub programs have also had many quality multi-investigator proposals well beyond the available funding level. This is indicative of tremendous untapped potential and research capacity in our universities and laboratories to tackle the energy innovation challenge.

Our judgment is that the funding scale advocated by the AEIC is about right. This increase will provide the U.S. with the potential to leapfrog to development and deployment of the advanced energy tech-

4. President's Committee of Advisors on Science and Technology (PCAST). (1997). *Report to the President on Federal Energy Research and Development for the Challenges of the Twenty-first Century*. Washington, DC: PCAST.

5. American Energy Innovation Council (AEIC). (2010). *A Business Plan for America's Energy Future*. Washington, DC: American Energy Innovation Council. Accessible at http://www.americanenergyinnovation.org/full-report.

nologies that will define a robust 21st century energy system. We stress that the actual funding will be, and should be, the result of bottom-up program construction, incorporating goals and objectives, milestones, human capacity building, appropriateness of government support, and other factors. The QER will be central to all of this. What is important about setting a funding scale is precisely the ability to put together the R&D portfolio in a manner commensurate with the importance of the challenge, strong management of the research program, and capacity to carry out the research.

RECOMMENDATION 3-1: We recommend that the President support annual expenditures on energy RDD&D of about $16B. To be effective, this funding must be long-term, stable, and have broad enough bipartisan support to survive changes of Administration.

It is worth noting that this level of expenditure is very similar to that advocated by the President during the 2008 campaign ($150 billion over ten years). At that time, the expectation was that the funds could be drawn from revenues generated by pricing carbon emissions. It seems likely that such funds will not be available in the near term, and yet there is urgency to ramp up to this funding level quickly. We return below to this challenge.

Not all of these funds would necessarily be expended through DOE. For example, large-scale demonstration projects could be carried out through DOE, perhaps with a dedicated office with authorities beyond those currently exercised by the applied energy research offices, or through a quasi-government corporation outside the department.[6] Similarly, the R&D funds could be managed entirely within DOE, or part could be managed by dedicated non-profit organizations with strong industry involvement and cost-sharing, with specific technology focus areas, and with appropriate government oversight of annual program plans. These organizational decisions should be taken on the basis of how the resources are provided, how the programs are structured, and how effective the programs are at generating progress. The QER will bring clarity to these choices. The key is to have oversight of the entire $16 billion as an integrated investment in accelerating energy technology innovation, even if part of the funds are best managed by quasi- or nongovernment entities.

The AEIC put forward a set of sensible key characteristics for program structure, drawn from successes with health and defense research funding:

- multiyear commitments in order to assemble talent and equipment and then achieve and validate results;
- pre-defined performance gates, and termination of unsuccessful projects;
- support for energy technologies with large-scale potential;
- Congressional funding of broad programmatic areas and competition within those areas; and
- concentrated goal-driven efforts, rather than fragmented programs.

6. Ogden P., Podesta J., and Deutch J. (2008). *A New Strategy to Spur Energy Innovation*. Washington, DC: Center for American Progress. Accessible at http://www.americanprogress.org/issues/2008/01/pdf/energy_innovation.pdf.

With regard to resources, we recognize that the discretionary budget is under severe pressure, so that a $10 billion or $11 billion annual increase in energy RDD&D would be nearly impossible to reach soon through the appropriations process. Without at least some "front-loading" of this increased investment, however, benefits are unlikely to accrue in the next decade.

RECOMMENDATION 3-2: We recommend that the President engage the private sector and Congress to generate about $10 billion per year of additional RD&D funding through new revenue streams. This can be accomplished through legislation or through regulatory mechanisms put in place with the collaboration of the engaged industries, state and local governments, non-governmental organizations, and consumer representatives.

Such revenue streams outside the appropriations process would not be new, except for the scale. A small surcharge on interstate natural gas transportation, approved by the Federal Energy Regulatory Commission (FERC), supplied a substantial budget for natural gas RD&D for many years. This budget was managed by the non-profit Gas Research Institute (GRI). The Board of Directors had requirements for industry and public representation, and FERC approved an annual program plan. More recently, Congress created a Royalty Trust Fund in the 2005 Energy Policy Act. This fund provides a small share of Federal oil and gas royalties for research on frontier exploration and production technologies and associated environmental protection. The funds are managed by a non-profit Research Partnership to Secure Energy for America (RPSEA), which is operated by a large industry-academia-national lab consortium and with DOE approval of the annual program plan. While different, the Electric Power Research Institute (EPRI) supported a very large research program through a cooperative effort with the electric industry and regulators. Both the GRI and EPRI funding suffered from deregulation. In recent years, there have been a number of initiatives in Congress, with some industry support, to implement such an approach. One proposal, for example, is a "line charge" on coal-generated electricity to produce a $1 billion per year RD&D fund for advanced coal technologies with carbon capture and sequestration. Cooperation between the President and the Congress is important if a statutory route is followed. Cooperation between the Administration and the energy industry, state and local governments, non-governmental organizations, and consumer representatives is important for a regulatory route, as was done for the FERC-approved R&D surcharge that led to GRI. A success of that approach, in tandem with DOE research funding and a synergistic tax incentive, is provided in the box on the following page.

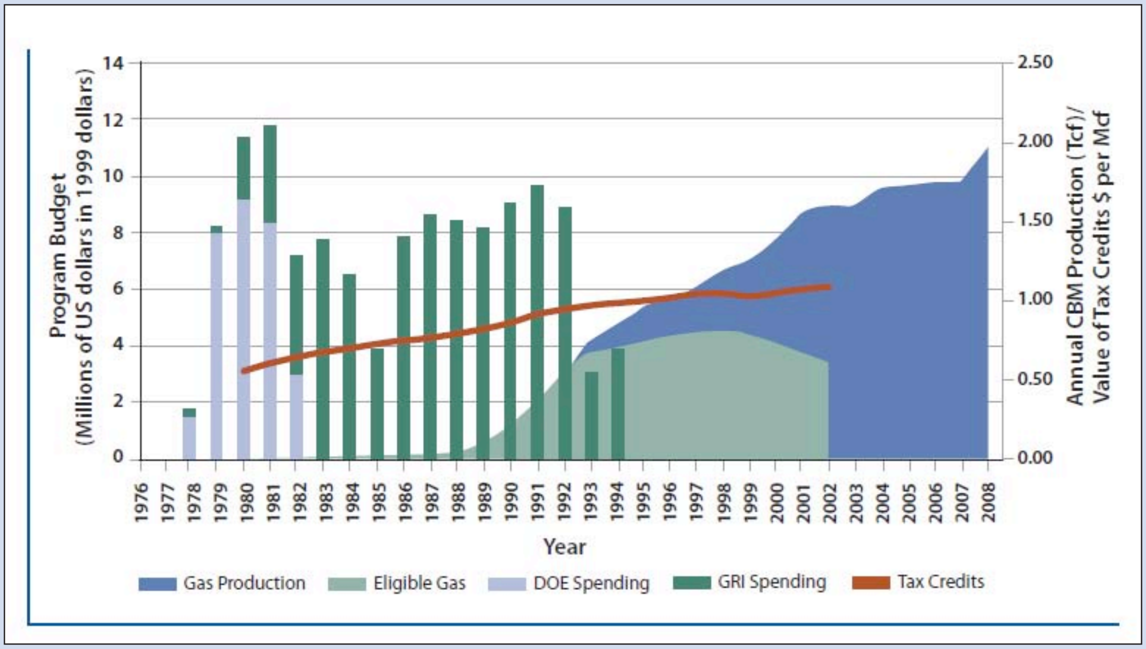
This example is suggestive of a broader point. The activity supported by GRI in this case was industry-led and had industry matching funds, appropriate for work that centered on the translation, adoption, and diffusion stages of the innovation chain. We view this type of innovation support mechanism not simply as a way to achieve the needed resource levels but also as a tool that is well-suited to many energy challenges that call for cooperation across an industry segment. This also reinforces the point that, while DOE is the lead energy R&D supporter, some parts of the portfolio are best managed differently, although most effectively when synergistic with DOE programs and with deployment incentives.

The scale of the energy charge is clearly important. About four trillion kilowatt-hours of electricity are used each year in the U.S., so a one mill/kWh charge would be sufficient to generate about $4 billion per year. Similarly, we use about 200 billion gallons of transportation fuel annually, so a two cents per gallon charge would also generate about $4 billion per year. These charges are well within the normal

COAL BED METHANE: A LARGE RETURN ON A SMALL INVESTMENT

The history of coal bed methane (CBM) offers an instructive example of how different RD&D and policy instruments can work together to produce important results. DOE's research program in reservoir characterization was followed by a larger, fifteen-year Gas Research Institute (GRI) program with industry cost-sharing. The GRI program was funded "off budget" through a small surcharge on interstate gas transportation administered by Federal Energy Regulatory Commission (FERC). The path forward was guided by industry input, especially the independent producers who led unconventional gas production and accomplished technology development, transfer, and testing. Simultaneously, tax credits were established for wells drilled from 1980 to 1992, with the credits extending to gas produced from those wells through 2002. The combination has raised CBM production from essentially nothing to 2 trillion cubic feet (Tcf) of gas per year (as depicted in Figure 2-1), with cumulative production of about 25 Tcf – a very large return on a relatively small RD&D investment.

FIGURE 3-2. COAL BED METHANE RD&D SPENDING AND SUPPORTING POLICY MECHANISM



The GRI (green) and DOE (red) invested more than $120 million (1999 dollars) combined in their respective RD&D programs for CBM between 1977 and 1994. Initial Section 29 Tax Credits for Non-Conventional Gas were equal to $0.52 per thousand cubic feet ($3 per barrel of oil equivalent) and were annually adjusted to inflation (purple). Approximately 9 trillion cubic feet of produced gas between 1980 and 2002 were eligible for the tax incentives as shown above (orange). Not all of the nominally available tax credits were exercised because of tax liability provisions (for instance, producers were not able to offset their Alternative Minimum Tax obligations, which affected approximately 50 percent of companies).

Source: Adapted from *The Future of Natural Gas: Interim Report (2010)*. MIT Energy Initiative. Cambridge, MA: MIT. Accessible at http://web.mit.edu/mitei/research/studies/report-natural-gas.pdf.

fluctuations in price seen by consumers and yet would provide a research fund that could materially lower future energy prices in a world conditioned by security and environmental concerns.

Rationalizing Incentives

Various subsidies and incentives for energy production, delivery, and use have a long history, going back at least to the oil depletion allowances put into law in 1913. These have always been justified as providing energy resources, technologies, infrastructure, or investments that would otherwise not be introduced at sufficient pace or scale. While these may all have had justification in their time, today's energy challenges and needs have clearly evolved substantially, particularly in the desire to move toward low-carbon technologies for both climate and security reasons. Ongoing subsidies that are misaligned with today's policy goals have the indirect effect of limiting new incentives aligned with Administration priorities. Those limits are manifest not only in the strength of the incentive that can be implemented in the short term but also, because of budgeting rules, in the length of time for which an incentive can be committed. The latter effect can lead to "stop and go" incentives that complicate private sector efforts to develop and deploy alternative energy technologies.

RECOMMENDATION 3-3: The Administration, led by the Council of Economic Advisors, should systematically inventory existing legislative energy subsidies and incentives with the intent of proposing a reallocation aligned with evolving priorities, as specified in the Quadrennial Energy Review.

The review should encompass multiple forms of energy subsidies, including:

- direct financial support (such as grants to producers or consumers and loan support);
- preferential tax treatment (such as tax credits, accelerated depreciation, and rebates or exemptions);
- trade restrictions (such as quotas, tariffs, and trade restrictions);
- energy-related services provided by government at less than full cost (such as direct infrastructure investment and liability coverage); and
- regulatory intervention (such as market access restrictions and mandated deployment).[7]

We note that the point of the exercise is not to eliminate subsidies and incentives, since these can be legitimate policy tools and some will certainly be embraced in the QER. Rather, the issue is to first understand the nature and extent of the subsidies and incentives and then to establish priorities, with a view toward advancing Administration objectives within budgetary constraints.

7. United Nations Environment Programme (UNEP). (2010). *Reforming Energy Subsidies: Opportunities to Contribute to the Climate Change Agenda.* Paris: UNEP.

Government as a Smart Energy Consumer

The Federal Government is a major consumer of both energy supply and products that consume energy. In 2008, the Federal Government consumed 1.1 percent of the 99.3 quadrillion Btu of energy used in the U.S., making it the largest consumer of energy in the country.[8] This energy was used to power everything from over 3.5 billion square feet of building assets to more than 600,000 vehicles in the Federal fleet.[9] According to DOE's *Annual Report to Congress on Federal Government Energy Management* (2007), DOD consumes more energy for its federal facilities and buildings than any other federal agency. In FY 2007, it spent almost $13.2 billion for energy (76.9% of total Federal energy expenditures).

Executive Order 13514 of October 5, 2009 was issued to spur the Federal Government to continue to use its purchasing power to create and move the energy marketplace. The Executive Order states the following:

> "In order to create a clean energy economy that will increase our Nation's prosperity, promote energy security, protect the interests of taxpayers, and safeguard the health of our environment, the Federal Government must lead by example. It is therefore the policy of the United States that Federal agencies shall increase energy efficiency; … leverage agency acquisitions to foster markets for sustainable technologies and environmentally preferable materials, products, and services; design, construct, maintain, and operate high performance sustainable buildings in sustainable locations; … and inform Federal employees about and involve them in the achievement of these goals. It is further the policy of the United States that to achieve these goals and support their respective missions, agencies shall prioritize actions based on a full accounting of both economic and social benefits and costs and shall drive continuous improvement by annually evaluating performance, extending or expanding projects that have net benefits, and reassessing or discontinuing under-performing projects."

Recently, the Federal Government has taken steps aligned with the Executive Order that illustrate the impact of its purchasing power. These include purchase of fuel efficient vehicles and use of alternative fuels to reduce greenhouse gas emissions from vehicles in the federal fleet, the opening of LEED certified buildings that reduce both energy and water consumption, and implementation of hybrid engines to reduce fuel consumption by DOD.[10] DOD and DOE have also issued and begun to implement a Memorandum of Understanding (MOU) to underscore their cooperation in enhancing the energy security of the U.S. This MOU includes activities such as evaluating energy systems and technology management solutions that meet DOD objectives, and maximizing DOD access to DOE technical expertise and assistance through cooperation in deployment and testing of emerging energy technologies. Despite these important steps, barriers still exist that prevent the Federal Government from maximizing the influence of its purchasing power.

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8. For more information, see http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_27.pdf and http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_5.pdf.

9. U.S. Government Accountability Office (GAO). (2009). *Federal Energy and Fleet Management: Plug-in Vehicles Offer Potential Benefits, but High Costs and Limited Information Could Hinder Integration into the Federal Fleet.* Washington, DC: GAO. Available at http://www.gao.gov/new.items/d09493.pdf.

10. For more information, see http://www.whitehouse.gov/sites/default/files/microsites/20100128-ceq-agency-stories.pdf.

RECOMMENDATION 3-4: To enhance the Federal Government's opportunity to advance energy technology innovation through its purchasing power, PCAST recommends that:

- **DOD, DOE, and GSA seek authority to increase the length of their contracts for purchasing power from renewable energy sources and Federal Agencies be given authorization to enter into energy-savings performance contracts (ESPCs) for leased, in addition to owned, facilities;**
- **when the Congressional Budget Office "scores" the budget for an energy supply or technology provision in a bill, it should spread that cost over the length of the contract so that the full financial benefits of technologies that enhance energy efficiency are incorporated; and**
- **the Office of Management and Budget (OMB) should develop criteria for determining life cycle costs and for including social costs in evaluating energy purchases, and should incorporate this methodology into agency procurements so that the Federal Government maximizes its influence on clean energy development that is most economic in the long term.**

For example, the Department of Defense has authority for only 10-year agreements for fuels supply. Furthermore, for low-carbon transportation fuels, actual agreements are typically for three years. The authorities for power and transportation fuels long-term contracts should be extended to 25 years, and the authorities should be exercised accordingly. It should also be noted that ESPCs, long-term federal contracts used for energy savings, have been very successful in achieving energy savings at federally owned facilities. If the maximum length of power and fuel agreements is extended and used to the full extent, and ESPCs are extended to federally leased facilities, the Federal Government will be better able to leverage its acquisitions to foster markets for emerging energy technologies, as directed by the President.

Leveraging International Collaboration

Climate change risk mitigation is inherently a global challenge. Indeed, long-term stabilization of greenhouse gas concentrations at prudent levels cannot be achieved without meaningful international collaboration. Energy security is also a global issue, with complex geopolitical concerns that both shape and constrain American foreign policy. Large-scale clean energy technology deployment in industrialized, emerging, and less developed economies is an essential response, one that can be advanced by renewed international technology cooperation. Carbon dioxide sequestration, development of unconventional natural gas resources in strategic locations, and market development for nuclear and renewable technologies are examples of important areas for collaboration. There is a common cause for significant cost reduction of low-carbon technologies, an essential outcome for adoption at scale in the less developed countries. Many Federal agencies can make key contributions.

RECOMMENDATION 3-5: The Office of Science and Technology Policy should reestablish the Committee on International Science, Engineering, and Technology (CISET) within the National Science and Technology Council (NSTC), with a strong focus on advancing the clean energy agenda. The committee should function at the Undersecretary level and be charged with developing an action plan aligned with the Administration's environmental, economic, and energy security objectives. Specific projects, assignment of agency leadership, and resource identification are essential elements of the action plan.

In the past, international cooperation on clean energy has too often taken the form of memoranda of understanding with little or no follow-through. But there are clearly areas of collaboration in which U.S. resources could be leveraged and progress toward economic technology deployment could be faster when working with international partners. Energy project goals should be elevated in priority with respect to a goal of international collaboration per se. The Undersecretary level is recommended to emphasize the priority of advancing real collaboration on key projects expeditiously and to provide the executive authority to carry forward and support the U.S. contribution.

IV. A New Era of Innovation at DOE

A prudent approach to mitigate the risk of climate change requires changes in policy. As stated in Chapter I, the invention, translation, adoption, and diffusion of clean energy technologies need to occur within one to two decades, not the 50 years characteristic of major energy systems. To achieve this accelerated pace of technological change, DOE needs to play a major role not just in energy RDD&D but in the formulation of Federal energy policy. DOE has an excellent leadership team in place with experience in energy RDD&D with members of the team experienced in industry, academia, national laboratories, and other government agencies. Work is currently being done on a number of important fronts: strategic planning and technology roadmapping; the development of multi-year program plans with detailed goals, metrics, milestones, and timelines; extensive system engineering; evaluations of program impacts; etc.

Support for Technological Change

In the previous chapter, we recommended that the energy technology innovation budget be increased to $16 billion. Of the $16 billion, the $12 billion for RD&D would largely increase DOE energy science and technology programs, although a portion could be managed externally, with strong industry input, in targeted areas and with DOE review and oversight (as described in Chapter III). A high priority is expansion of innovative new programs such as the Energy Frontier Research Centers (EFRCs, in Basic Energy Science), ARPA-E, the Energy Innovation Hubs (in various science and energy offices), and Bioenergy Research Centers (BRCs). These programs largely incorporate the key program characteristics outlined by the AEIC and have had strong peer review selection processes. While it is too early to evaluate the long-term impact of these new programs, we applaud the initiation of new ways of advancing the innovation agenda. We also note that the EFRC, ARPA-E, Hub, and BRC programs constitute an interrelated set of multiyear commitments to energy science and technology, and that their establishment spans the previous and current Administrations. Congress also has played an active role in advancing this agenda, especially with ARPA-E. This history offers hope that these innovation programs will enjoy stable bipartisan support and multiyear funding commitments.

The recently released National Research Council (NRC) reports[11] found that although there are technologies that can increase energy efficiency and supply new energy for the next decade, RD&D is needed to fill the pipeline with new technologies to be implemented after 2020. The report stated that to meet this need, both the public and private sectors will need to perform extensive RD&D over the next decade. Since there is a range of uncertainties in the development and deployment of new technologies, a portfolio is needed that supports a wide range of initiatives from basic research through demonstration; this would be more effective than targeted efforts to identify and select technology winners and losers. Suggested technology RD&D topics are provided in the Academy reports for energy efficiency and for supply options.

11. NRC. (2009). *America's Energy Future: Technology and Transformation*. Washington, DC: National Academies Press. NRC. (2009). *America's Energy Future: Real Prospects for Energy Efficiency in the United States*. Washington DC: National Academies Press. NRC. (2009). *America's Energy Future, Electricity from Renewable Resources*. Washington DC: National Academies Press.

As discussed in Chapter III, given the overall constraints on the Federal budget, part of this funding will probably need to come from other sources. The Administration should work with industry and consumer representatives and with the 112th Congress to determine the most effective way to fill the roughly $11 billion gap between this year's appropriations request for DOE and the recommended funding level.

A series of consistent metrics across all of DOE energy programs should be developed and implemented to monitor progress in stimulating energy innovation, to determine whether the benefits justify the expenditure of public funds, to make adjustments for new conditions, and to maintain accountability. Regular external reviews of programs should be conducted, and programs not meeting milestones should be considered for termination.

Retrospective studies determining the economic, environmental, and security benefits of completed programs should be initiated and the projects tracked for a reasonable number of years. Retrospective studies conducted so far have shown that DOE programs have been effective and have shown real benefits.[12] DOE has not focused sufficiently on outcomes research that can provide guidance for making future decisions on the RD&D portfolio.

DOE spent more than $7 billion (in 1999 dollars) on all of its energy efficiency RD&D programs during 1978-2000. Some of the most successful programs were in a number of building energy efficient technologies including high efficiency appliances, electronic lighting ballasts, and low–emissivity windows, which have yielded net benefits of around $30 billion. The industrial energy efficiency program has saved about 3 quads of energy cumulatively and about 0.4 quads in 2005 alone.[13] In the above mentioned NRC Retrospective study, the fossil energy program recognized economic benefits of nearly $11 billion (in 1999 dollars) over the same 22 year period covered. Some of these savings were attributed to costs avoided by demonstrating that more stringent environmental regulation was unnecessary for waste management and for addressing airborne toxic emissions. The coal bed methane program described in Chapter III is an example of a DOE program with a large return.

RECOMMENDATION 4-1: Of the $16 billion that we recommend for energy innovation in the Administration's FY 2012 budget request, $12 billion should be for RD&D funding, with emphasis on DOE competitive programs. The Federal appropriated level should remain at least at the FY 2011 request of $5.1 billion. The additional RD&D funds of $7 billion should come from new revenue streams. For the near term, these funds could come from small charges on energy production, delivery, and/or use. In the intermediate and long term, they could come potentially from carbon dioxide emissions pricing. Funding should be consistent over multiyear time periods, and multiyear funding should be instituted with appropriate milestones and decisions points that are reviewed annually.

12. NRC. (2001). *Energy Research at DOE: Was It Worth It?* Washington, DC: National Academies Press.
13. DOE. (2007). *Impacts. Industrial Technologies Program: Summary of Program Results for CY 2005*. Washington, DC: Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program.

Organization, Administration, and Processes

DOE has a broad range of authorities over its organization, administration, and processes. To accelerate and focus technological change, DOE needs to implement these authorities and exercise its legislated flexibility.

RECOMMENDATION 4-2: The Secretary of Energy should implement the full range of authorities to streamline and focus on energy objectives by:

- **extending processes and procedures used successfully in ARPA-E to all DOE energy programs;**
- **managing demonstration projects so as to adhere to private sector practices to the maximum degree possible;**
- **working with OMB to streamline awards, including loan guarantees;**
- **reviewing the national laboratories' capabilities for twenty-first century energy innovation;**
- **replacing the existing Office of Energy Policy and International Affairs with an independent Office of Energy Policy headed by a director and an Office of International Affairs that would continue to be led by an Assistant Secretary; and**
- **making other organizational changes to increase the focus on energy goals.**

Building on the Success of ARPA-E. In its short history, ARPA-E has demonstrated that it is possible to have an agile and effective technology program within DOE. It has streamlined the contracting processes and has assembled a high-quality program management team. It has demonstrated that streamlined processes can attract superb individuals and teams to make proposals. To accelerate the transformation of the energy system, excellent people need to be engaged in government programs and work on energy technologies. To sustain this success, it will be important to extend this streamlined approach to project execution as well.

Specific features of ARPA-E's success include:

1. A rigorous review process.
2. Contract or grant negotiations completed in just a few months.
3. Co-location within the program offices of such support functions as procurement, contracts, human resources, and information technology services.
4. Use of all contracting methods and authorities, including Other Transaction Authority (OTA).
5. Modification, as appropriate, of the 20 percent matching requirement for the applied energy research program for universities and non-profit entities.
6. An agile and innovative workforce.

To extend these and other features to all DOE energy programs, the Administration should request that Congress extend the OTA authority for DOE and give DOE straightforward OTA authority, instead of casting this authority in terms of DOD's authority. DOE programs and offices also need hiring authority similar to that of ARPA-E to attract an innovative professional workforce. Program directors should be enabled to have finite terms. And a DOE fellows program should be created to make use of the Intergovernmental Personnel Act Mobility Program to attract individuals from both universities and industry.

In addition, the Administration should work to eliminate the 20 percent matching requirement for applied energy research program for universities and non-profit entities. Small business start-ups should be given up to six months after award to acquire matching money of 10 percent. (ARPA-E reduced funding for all of the above to 10 percent.) Non-start-up private sector businesses would be expected to continue to contribute a 20 percent match. The overarching point is that the Secretary should use his authorities to have matching fund requirements "fit to purpose."

Managing Demonstration Projects. The previous chapter included recommendations about the management of large-scale demonstration projects such as carbon capture and sequestration and next generation nuclear power plants. Small-scale demonstrations such as those typically funded in the energy efficiency and renewable programs should continue to be managed within the core programs of DOE.

Working with OMB. The Secretary of Energy and the Director of OMB should continue to work together to ensure that OMB helps to expedite DOE's implementation of its authorities, such as loan guarantees, OTA, and cost-sharing, and does not impose any barriers to the exercise of DOE's authorities and flexibility. Currently, OMB conducts an extensive and time-consuming review of each loan guarantee made by DOE. Under the Credit Reform Act, OMB has the authority to delegate loan guarantee reviews to the agencies, and it does so with some agencies such as the U.S. Department of Agriculture. DOE and OMB should develop criteria to assess the risk of a loan guarantee project, and OMB should expedite those with lower risks or delegate their review to DOE.

Establishing a Dedicated Policy Office. DOE has a great need for a dedicated policy office that could report to and advise the Secretary and interact with the White House energy policy staff. When DOE was created in the 1970s and during the Clinton Administration in the 1990s, there was a separate office for policy and one for international affairs. The existing office combines international and policy affairs, and these call for rather different backgrounds and expertise. The Secretary should instead create an independent Office of Energy Policy headed by a director who is a political appointee and reports to the Secretary. It will provide critical counsel and support to the Secretary in carrying out the Executive Secretariat role for the Administration-wide QER. Such an office could also develop policies to accelerate the adoption and diffusion of technologies; recommend the appropriate agencies to implement policies; identify effective regional, state, and local programs and implement similar programs nationwide; and provide leadership and feedback to regional, state, and local energy agencies. This office could also develop and implement a series of consistent metrics across all of DOE energy programs. The office will need deep familiarity not only with Federal policy but also with energy technology, the energy industry, and state regulatory bodies. To meet these obligations, it is important that creation of the Policy Office be accompanied by a substantial expansion of the professional energy policy staff.

A separate Office of International Affairs would, as is now the case, be responsible for coordinating international collaboration within the department and developing international energy policy in conjunction with other Federal agencies. The growing importance of international collaboration and of international energy security concerns will be well served by a dedicated office. This office should continue to be led by an Assistant Secretary.

Reorganizing Energy Offices. Other organizational changes could increase the focus of DOE on energy goals. The current DOE organization structure was put in place in the 1970s. The energy market structure was very different than now (e.g., oil was important not only for transportation, but also for electricity generation; there is a greater diversity of supply today; futures markets developed; wholesale electricity markets "deregulated"). With the move to low carbon technologies, there is implied a move from the resource extraction basis for energy supply to a technology focus and different business structures (e.g., electricity for transportation; subsurface science for coal power plants with carbon capture and storage). We recognize that organizational changes are difficult both from the perspective of the current workforce and the external community with whom there have been long-term relationships. But it is important to undertake a bottom-up review. The Secretary of Energy, with appropriate Congressional consultation, should evaluate organization arrangements that may best align departmental roles for the new energy challenges. This bottom-up review of the organization and authorities could be undertaken with the assistance of SEAB. For example, in the future, the department could have one Undersecretary for Energy and Science and a second Undersecretary for Operations, including Environmental Management. This will help with the integration of energy and science and also provide a focus for operations and organizational challenges. DOE also could separate energy efficiency and renewable energy, ideally both with Assistant Secretaries, since these are both critical programs and call upon different technologies, policies and experience. When DOE was created, these programs were relatively new efforts. They are now mature programs with different technologies, manufacturers, customers and barriers to innovation. The recent integration of nuclear energy and nuclear waste management under one assistant secretary was a good step. A larger step in the future would be to align the energy offices closer to end-use and delivery rather than "fuels"; this would recognize the different business structures that will evolve with new technology (e.g., electricity and biomass as transportation "fuels"). DOE already has the authority to carry out such reorganizations and should initiate the suggested review.

Workforce Development

DOE needs to optimize its workforce development programs to provide the intellectual resources needed for energy technology change in the 21st century. The next generation of scientists and engineers must be trained with a new set of tools to address critical issues such as climate change, energy security, water scarcity, pollution, ecological degradation, and biodiversity loss simultaneously. This will require new kinds of M.S. and Ph.D. educational programs and an increased focus on traineeships. The traineeship model aligns well with the mission orientation of DOE.

RECOMMENDATION 4-3: DOE should establish a training grant program at universities similar to the NIH and NSF training grant programs. These programs would address critical energy workforce needs in such areas as power electronics, energy storage, radionuclide chemistry, and combustion, and the related areas of IT, social sciences, etc. These would support not only graduate students but also curriculum development, postdoctoral researchers, integrated departmental programs, and undergraduate support.

An example of an effective traineeship program is the Integrative Graduate Education and Research Traineeship (IGERT) program at the National Science Foundation. IGERT provides Ph.D. students in science and engineering with interdisciplinary training and collaborative experiences designed to provide students with the tools to become future leaders. Independent evaluations of the program indicate that it is helping to catalyze a cultural change in graduate education and is diversifying the research and collaborations of faculty members as well as students. In addition, the America COMPETES Act authorized NSF funding of professional science master's programs which prepare graduate students for careers in business, industry, nonprofit organizations, and government agencies by providing them not only with a strong foundation in science, technology, engineering and mathematics (STEM) disciplines, but also with research experiences, internship experiences, and the skills to succeed in those careers.[14] A similar DOE program could focus on energy workforce needs. DOE also should consider augmenting its principal investigator research funding program to include not just Ph.D. students but also master's degree students working in relevant fields. Hubs, centers, and other institutions supported by DOE are ideal locations for traineeships along with academic institutions. In addition, a postdoctoral program, focused on universities and non-profit organizations, should be developed for energy research, both basic and applied.

A Multidisciplinary Social Science Research Program

DOE's energy mission is to support basic and "use-inspired" research, but in fact it devotes little time or investment to understanding how energy technologies ultimately succeed in the marketplace. DOE needs to "close the innovation cycle" through support of a significant new multidisciplinary program into the processes of energy innovation. Understanding how the department's technologies proceed as they pass from invention to innovation to adoption to diffusion and how the innovation system as a whole is functioning is critical to understanding the overall success of DOE's mission, as well as the performance of government in energy innovation and technology deployment.

RECOMMENDATION 4-4: DOE, along with NSF, should initiate a multidisciplinary social science research program to examine the U.S. energy technology innovation ecosystem, including its actors, functions, processes, and outcomes. This research should be fully integrated into DOE's energy research and applied programs.

14. For more information, see http://www.nsf.gov/pubs/2009/nsf09607/nsf09607.htm.

This research program should fund experts from the physical sciences, engineering, economics, sociology, public policy, political science, international relations, business, and other disciplines. Examples of questions that might be rigorously studied are:

- How and why are advanced energy technologies accepted or rejected by consumers?
- What are the barriers to adoption?
- Will the public accept a specific technology and why?
- What market conditions are needed for a technology to compete?
- What is the role of public policy to efficiently and effectively push and pull advanced technologies into the marketplace?
- How are technologies transferred and diffused internationally?

Other types of multidisciplinary research that are needed include strategic energy analyses and full life cycle assessments of new energy technologies. The potential benefits of such a research program are significant. Estimates are as high $1.2 trillion in energy savings through 2020 from wide scale implementation of energy efficiency technologies in the U.S.[15] With or without new technologies, more behavioral research is also needed concerning the patterns, incentives, and decisions that determine individuals' energy usage. Well-designed social science experiments can yield important insights about how people react to various policies and technologies. Continuity is important. In many cases, large-scale datasets exist or can be easily collected concerning such questions, but are not easy to study because of proprietary or regulatory obstructions. DOE should work with OMB, energy providers, and researchers to facilitate the compilation of energy usage data under both routine and experimental conditions. Other disciplines, such as history and international case studies, can also deliver important lessons.

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15. McKinsey & Company. (2009). *Unlocking Energy Efficiency in the U.S. Economy.* Milton, VT: Granade, H.C., J. Creyts, A. Derkach, P. Farese, S. Nyquist, and Ostrowski, K. Available at http://www.mckinsey.com/clientservice/electricpowernaturalgas/downloads/us_energy_efficiency_full_report.pdf.

Appendix A: Statement of Task

President's Council of Advisors on Science and Technology Study on the Energy Technology Innovation System

Major challenge: acceleration of large-scale transformation of the energy production, delivery, and use system to low-carbon, at a pace commensurate with significant climate change risk mitigation.

Overarching question for the study: What is the Federal government research, development, demonstration, and deployment (RDD&D) role to effect such a transformation? How can that role best be implemented in the near-term and in the long-term, including through partnerships with states, industry, academia, investors, and other participants in the innovation system? Would a reorganized DOE RDD&D be more effective? If so, how should it be organized? What steps can be taken within current statutory authorities?

Analysis elements:

- government-wide with a DOE focus
- system view of ARRA, EFRCs, ARPA-E, Innovation Hubs, and traditional DOE energy technology and science programs
- university-laboratory-industry balance and synergies/engagement of best scientists and engineers in energy science and technology innovation
- process issues: contracting, procurement, responsiveness, and personnel recruitment
- alternative mechanisms and balance in RDD&D: peer reviewed grants, contracts, centers, cost shared projects, prizes, and "off budget" funding
- organizational issues: statutory vs. non-statutory requirements; universities and cost sharing; rewarding rational risk-taking; and promoting collaboration of applied energy programs with each other and with others (Office of Science, ARPA-E, etc.)
- adequacy of resources (funding, people, tools, etc.)
- role of other agencies in the energy technology innovation system (NIST, NSF, DOD, USDA, EPA, DOI, etc.) and multiagency coordination
- analysis of appropriate role of government in technology and markets, including an analysis of when support should change or conclude

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