ISSUE BRIEF 9

CLIMATE TECHNOLOGY RESEARCH, DEVELOPMENT, AND DEMONSTRATION: FUNDING SOURCES, INSTITUTIONS, AND INSTRUMENTS

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9

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SUMMARY

There is growing consensus among policymakers and stakeholders that an effective federal program to reduce greenhouse gas (GHG) emissions should include polices that hasten the development and commercialization of low- and no-carbon energy technologies, as well as technologies that increase end-use energy efficiency. Alongside policies such as a GHG cap-and-trade system that would directly mandate emissions reductions, policies that would instead target innovation and investment in GHG-reducing technologies have been much discussed. While both types of policies may be motivated by concerns about climate change, technology policies are generally framed in terms of technology-development activities or technology-specific mandates and incentives rather than primarily in terms of emissions.

A wide range of options for promoting climate-friendly technologies is currently being employed or proposed at the federal and state levels. It is useful to roughly categorize these options according to which stage of the technology-innovation process they target: research, development, and demonstration (RD&D) or commercial deployment. After exploring various rationales for technology policy, this issue brief examines the funding sources, institutions, and policy instruments that have a potential role to play in enhancing RD&D efforts to advance climate change mitigation and adaptation technologies. A companion issue brief addresses options for promoting technology deployment, including mandates, financial incentives, and enabling regulations.

A number of important messages emerge:

- An emissions price established through a GHG cap-and-trade or tax system would induce firms to invest and innovate in developing technologies that reduce emissions more effectively and at lower cost.

- Nonetheless, several motivations exist for including additional RD&D policies as complements to a pricing policy in a comprehensive strategy to address climate change. R&D tends to be underprovided in a competitive market because its benefits are often widely distributed and difficult to capture by individual firms. Given the likelihood that the magnitude of GHG reductions needed to address climate concerns will increase significantly over time, private-sector investment in technology innovation is likely to fall short of what may be desirable over the long term, particularly given the fragility of expectations concerning future GHG prices and the uncertain credibility of near-term policy commitments. Ensuring that capable, university-trained researchers will be available to the public and private sectors in the future provides another compelling motivation for public spending on technology R&D, especially given the importance of investing in human capital to maintain long-term economic competitiveness.

- While public funding for research tends to be widely supported, there is less agreement about the justification for public-policy intervention (beyond the emissions

price) as one moves from basic R&D to the demonstration and deployment phases of technological innovation.

- Although particular energy RD&D programs have produced some notable failures and although their performance has varied widely, studies have found that federal energy R&D investments have on the whole yielded substantial direct economic benefits as well as external benefits such as pollution mitigation and knowledge creation. Government-sponsored energy R&D programs are also commonly thought to have improved substantially since the 1970s and early 1980s—both in terms of the way they are managed and in terms of the objectives they target—as their emphasis shifted from energy independence and large-scale demonstration projects to environmental improvement, precommercial research, public-private partnerships, and cost-sharing. Private industry involvement is almost always mentioned as being very important, particularly as new technologies approach the commercialization stage.

- Substantially boosting efforts to develop and deploy low-GHG energy alternatives would require a sustained increase in RD&D funding and increased market demand for associated technologies (where increased demand would likely be due, at least in part, to the concurrent implementation of policies that provide an economic incentive for reducing GHG emissions). Increased funding could come from general revenues through the standard appropriations process, from revenues generated by emission taxes or the sale of emission allowances, or from wires and pipes charges on electricity and other fuels. Alternatively or in addition, increased investment could be induced through more generous R&D tax credits. Because associated revenues may be less likely to be diverted for other budget purposes, allowance sales or wires and pipes charges, or both, are likely to provide the largest and most stable dedicated funding stream.

- Numerous existing institutions are engaged in energy RD&D, including the U.S. Department of Energy (DOE), DOE's national laboratories, the National Science Foundation (NSF), universities, individual firms, private research consortia, and non-profit research institutions. These institutions vary both in terms of their roles in funding versus performing research and in terms of which stage(s) of the innovation process they primarily engage (i.e., basic research, applied research, development, and demonstration). The existing system of institutions involved in energy innovation is best characterized as an interconnected network of entities with different and somewhat overlapping roles—it does not have a highly unified or linear structure.

- A number of objectives are frequently noted in relation to public investments in RD&D. These include effective and efficient management and performance, stable funding, insulation from politics, and public accountability. Some of these aspirations are mutually reinforcing, while others may conflict.

- Regarding the *administration* and *coordination* of federal energy RD&D, greater concern is typically expressed about existing institutional capacity to manage an expanded funding base for *applied* RD&D than about the ability of existing government institutions (such as the DOE Office of Science, the NSF, and the National Institute of Standards and Technology) to effectively administer increased funds for *basic* research. The existing suite of institutions that actually perform RD&D—including universities and other non-profit institutions, the national laboratories, and private firms—seems sufficiently broad to handle an increase in funding, although capacity would need to deepen if considerable expansion of current research efforts was desired.

- The main institutional options for administering an expanded public investment in applied energy RD&D are the existing DOE program offices (i.e., Energy Efficiency and Renewable Energy, Fossil, and Nuclear), a new government agency or agencies (for example, recent proposals have called for an energy version of the Defense Advanced Research Projects Agency or "ARPA-E" and a Climate Technology Financing Board), a new quasi-public corporation (recent proposals refer to a new Energy Technology Corporation or Climate Change Credit Corporation), and/or private research consortia. These options differ in terms of how likely they are to meet the range of policy objectives mentioned above (e.g., efficiency and accountability)—in perception and in practice.

- The primary mechanisms that have historically been used to deliver public support for RD&D—including contracts, grants, and tax credits—will continue to play a central role, perhaps with some incremental modifications. Technology innovation prizes represent a new opportunity for expanding the range of instruments used to provide RD&D incentives; both the private and public sectors are currently experimenting with this approach.

The Role of RD&D Policy

R&D encompasses activities associated with discovering new knowledge and applying that knowledge to create new and improved products, processes, and services—in this case with the aim of reducing GHG emissions.[1] Demonstration projects, on the other hand, test the feasibility of GHG-reducing technology at a scale that is closer to what would be employed in wider commercial deployment.

When considered alongside policies that impose mandatory GHG-reduction requirements, additional technology policies may not seem necessary or desirable. After all, the point of market-based approaches is to establish a price on GHG emissions. This price in turn attaches a financial value to GHG reductions and—just as people will consume less of something that carries a price than they will of something that is given away for free—should induce households and firms to buy technologies with lower GHG emissions (a more efficient appliance, for example) the next time they are in the market. This market-demand pull should in turn encourage manufacturers to invest in R&D efforts to bring new lower-GHG technologies to market, just as they do for other products and processes.

There are nonetheless several rationales or motivations for considering technology-oriented policies within a portfolio of climate policies that also includes pricing emissions. The economics literature on R&D points to the difficulty firms face in capturing all the benefits from their investments in innovation, which tend to spill over to other technology producers and users. This market reality can lead to under-investment in innovative efforts—even given intellectual property protection—potentially warranting policies that directly target R&D. In a related manner, the fact that knowledge can be relatively inexpensive to share once it is produced raises the possibility that coordinated public R&D programs can conserve resources by reducing duplicative efforts.

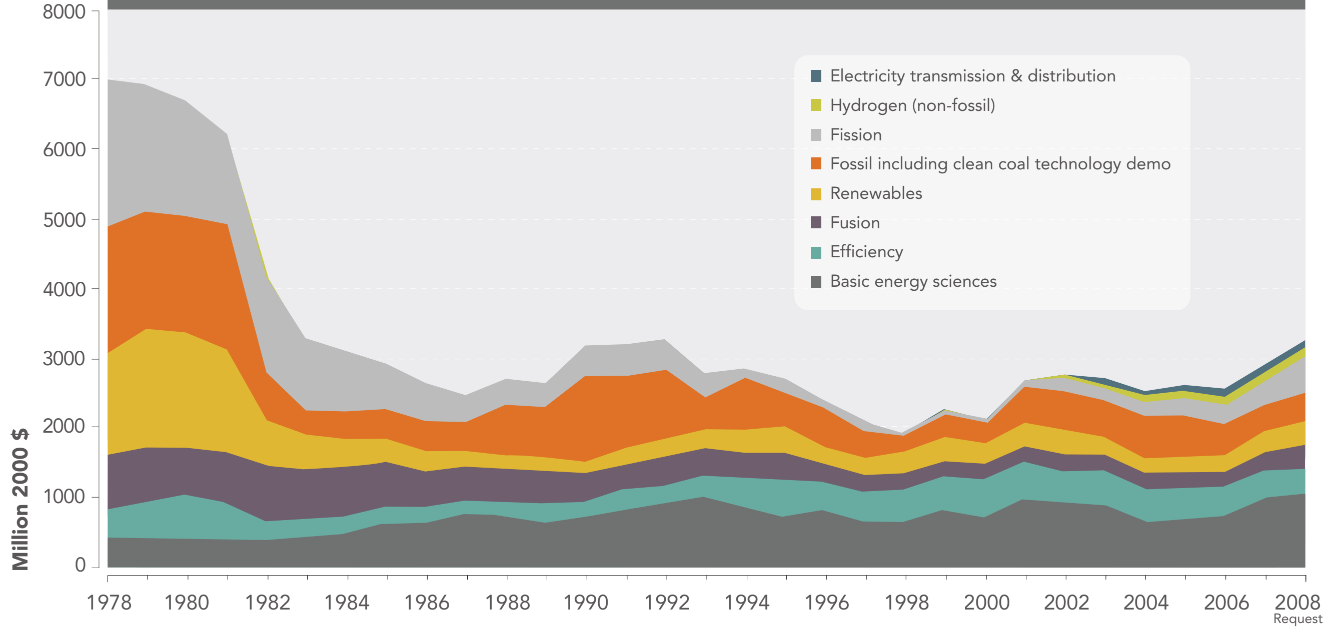
The problem of private-sector under investment in technology innovation may be exacerbated in the climate context where the energy assets involved are often very long-lived and where the incentives for bringing forward new technology rest heavily on domestic and international policies rather than on natural market forces. Put another way, the development of climate-friendly technologies has little market value absent a sustained, credible government commitment to reducing GHG emissions. Moreover, the mismatch between near-term technology investment and long-term needs is likely to be even greater in a situation where the magnitude of desired GHG reductions can be expected to increase over time. If more stringent emissions constraints will eventually be needed, society will benefit from near-term R&D to lower the cost of achieving those reductions in the future. An emissions price that is relatively low in the near term may be inadequate to induce such innovative efforts absent very credible expectations that the policy will indeed be tightened in the future. If the politically feasible near-term emissions price (and/or the expected long-term emissions price) is lower than the socially optimal level, market inducements for R&D on GHG-reducing technologies will also be insufficient.

Similarly, rationales for public support of technology demonstration projects tend to point to the large expense; high degree of technical, market and regulatory risk; and inability of private firms to capture the rewards from designing and constructing first-of-a-kind facilities. These motivations provide potentially compelling rationales for public policies targeted at the R&D (research, development) and D (demonstration) phases of the technology innovation process. In addition, by virtue of its critical role in the higher education system, public R&D funding will continue to be important in training researchers and engineers with the skills necessary to work in either the public or private sectors to produce GHG-reducing technology innovations. By supporting graduate students and post-doctoral researchers, public funding for university-based research will affect the economy's capacity to generate scientific advances, technology innovations, and productivity improvements in the future. This linkage has made research funding a priority among many who are concerned about the long-term competitiveness of the U.S. economy and has led to a recent increase in political support for expanded spending—particularly on physical sciences and engineering.

In contrast, critics of public funding for RD&D pose the concern that government is ill-positioned to "pick winners" among a broad array of technological possibilities and commercial opportunities. They argue that decisions about how to invest in technology innovation are best left to a private sector motivated through broad incentives such as a price on GHGs. Even granting that a legitimate economic rationale

1 The National Science Foundation (NSF) defines research as "systematic study directed toward fuller knowledge or understanding," with *basic* research being directed toward the "fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind." *Applied* research, by contrast, is directed toward determining "the means by which a recognized and specific need may be met." Development is defined by NSF as "systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements." See NSF. 2007. *Federal Research and Development Funding by Budget Function: Fiscal Years 2005-07*. Washington, DC: NSF.

Figure 1 U.S. DOE Energy RD&D (FY1978-FY2008)



for public involvement exists *in theory*, critics assert that the practical import of most such programs is negligible and likely to be more than offset by the cost and waste associated with pork-barrel spending and unnecessary government intrusion into the market. At a minimum, these critiques point to the importance of designing institutions, instruments, and incentives for delivering publicly supported RD&D in ways that minimize the risk of producing undesirable outcomes.

Despite some well-know failures, however, studies typically find that federal energy R&D investments have, on the whole, yielded substantial direct economic benefits as well as external benefits such as pollution mitigation and knowledge creation (a later section of this issue brief provides more detail on U.S. DOE programs). Nonetheless, and even given increasing concerns over global climate change, investment in energy R&D began to increase again only recently following a dramatic decline in both public- and private-sector spending over the last three decades. In that time period, low fossil-fuel prices and the deregulation of the natural gas and electric utilities industries led to substantial reductions in private-sector R&D expenditures, while efforts to balance the federal budget and a lack of political interest prevented the federal government from offsetting this decline. U.S. DOE expenditures on energy RD&D, including basic energy sciences, now total slightly more than $3 billion annually. This is less than half, in inflation-adjusted terms, of the peak level of spending reached in 1978 (see Figure 1). Identifying potential sources of funding for an expanded federal investment in technology RD&D therefore represents an important challenge for policymakers, as discussed in the next section.

Overall, public funding for research tends to receive widespread support based on the significant positive spillovers typically associated with the generation of new knowledge. Agreement over the appropriate role of public policy in technology development tends to weaken, however, as one moves from support for research and development to support for demonstration projects and particularly deployment. For most standard market goods, economists and other experts generally see clear justification for a government role in supporting research, but much weaker rationales for government intervention in the realms of technology commercialization and widespread deployment.

RD&D Funding Options

A major concern for any RD&D program is funding.[2] Decisions

2 This section benefited greatly from Nordhaus, R., et al. 2004. Public Sector Funding Mechanisms to

about the funding source(s) to be used for these programs have consequences for the magnitude, availability, and continuity of financial support in the future. They can also have implications for the institutional management of funds as well as the degree and nature of government oversight. This section discusses potential sources of funding for an expanded federal role in climate-related technology RD&D, including funding through general revenue, dedicated revenue (for example,from the sale of emission allowances), or wires and pipes charges. Institutional options for administering and performing publicly supported RD&D are discussed in the next section, while the use of tax credits as a mechanism for funding private-sector R&D efforts is discussed in the final section.

General Revenue

One option for funding federal RD&D efforts is to rely on general revenues disbursed via Congressional appropriations through the U.S. Treasury. The year-to-year nature of the appropriations process can, however, be detrimental to long-term planning. Agencies can enter into multi-year agreements, but their financial commitments cannot exceed their current fiscal year appropriation. Options do exist that would allow for some long-range planning: for example, the government can use advance appropriations to commit specific amounts of funding for future years. Congress is generally averse to such pledges, however, because they constrain future appropriation options; moreover, promised funds are also easily rescinded. Another option is lump-sum appropriation in which all funding to be provided over the life of a program is made available in the year of enactment. This scheme provides some measure of stability, though any money carried over from year-to-year is still vulnerable to redistribution for other projects.

Dedicated Revenue, Including Revenue from the Sale of Emission Allowances

By establishing a dedicated revenue source, Congress could help to avert some of the problems associated with relying on general revenues. A dedicated tax on some aspect of energy generation, distribution, or consumption could help fund R&D if resulting revenues were placed in a trust fund, as per the Highway Trust Fund. The federal government can be contractually required to allow the administering agency to draw down the fund. Also, appropriations committees can be restricted from spending at a level below receipts in an attempt to redistribute extra funds for other purposes. This is not the case with all trust funds, however. The Nuclear Waste Fund, for example, is subject to annual appropriations. Since most climate-policy proposals introduced in Congress have focused on limiting GHG emissions through a cap-and-trade program (rather than by taxing emissions), any associated revenue stream that could potentially be available for RD&D would come from allowance sales. Several current proposals set aside at least a portion of revenues from auctioning allowances or from the direct sale of allowances at a fixed price under an emissions-price ceiling (that is, a safety valve) to support technology RD&D and deployment incentives. Typically, this results in a targeted funding stream on the order of several billion dollars annually, and up to $50 billion or more in total over multiple years of program implementation (with total amounts limited in some proposals mainly by funding caps). Targeting revenues from allowance sales under a safety-valve mechanism to technology development has the environmentally appealing feature that lesser near-term emissions reductions (due to the safety valve) help to pay for expanded investments in future abatement potential. In fact, one recent legislative proposal uses the term "Technology Accelerator Payment" to refer to safety valve payments. On the other hand, targeting expected revenue streams to any particular purpose in advance runs counter to a longstanding principle of public finance that favors separating revenue sources from spending.

For example, the Bingaman-Specter "Low Carbon Economy Act of 2007" (S. 1766, 110th) would establish an "Energy Technology Deployment Fund" within the Treasury. Revenues from allowance sales would be deposited into this fund to be used for zero- and low-carbon technology deployment. Another example is the Lieberman-McCain "Climate Stewardship and Innovation Act of 2007" (S. 280, 110th), which would establish a new entity called the Climate Change Credit Corporation (CCCC) to receive and disburse GHG allowances and resulting revenues. Some of these revenues would be used to support a new technology deployment program, the Climate Technology Challenge Program. One potential distinction between these and other related proposals is whether allowances and/or funds from the sale of allowances are actually disbursed by a government agency through the Treasury or directly allocated to and disbursed by a quasi-governmental non-profit corporation.

In either case, it is important to note that new funding in both of these legislative proposals is actually directed to technology *deployment*, rather than research. For this reason, the more significant legislation for energy R&D may be the recently enacted America Competes Act (S. 761 and HR.

Support the Implementation of a U.S. Technology Strategy. GTSP Working Paper 2004-07 (PNNL-14780). College Park, MD: Pacific Northwest National Laboratory.

2272, 110th) which, among other things, authorizes a very substantial increase over the next several years in the budget for physical sciences and engineering research in DOE's Office of Science, the NSF, and the National Institute of Standards and Technology (NIST). In addition, this bill establishes an Advanced Research Projects Agency-Energy (ARPA-E) within DOE (see further discussion later in this issue brief). The degree to which future appropriations will support these authorizations remains to be seen.

Wires and Pipes Charges

Using dedicated fees on electricity, natural gas, or other forms of energy—sometimes referred to as wires and pipes charges—could help fund RD&D within or outside the normal appropriations process. By levying surcharges on the transmission and distribution of electricity and/or natural gas, or as part of federally regulated rates for transporting oil, coal, or other fuels, Congress could establish a stable source of funding for energy-technology investments. This is closely related to the approach of using electricity wires charges for "public benefit funds" that in turn support energy efficiency programs and related research activities (states that currently have such funds include New York and California). Another example is the Universal Service Fund, which was established by the Telecommunications Act of 1996 and which uses fees on telephone services to promote wider access to telecommunications.

In principal, the proceeds from a wires charge could flow to any number of different institutional entities, including a federal trust fund, state agencies, a quasi-governmental corporation, private research consortia, or to the collecting firm (such as the distribution utility in the case of a fee on electricity services) for approved purposes. One potential problem is that it could be administratively difficult to levy fees in cases where carbon-containing fuels are not subject to existing transportation rate regulation. It may also be desirable to harmonize the relative charge across various fuels (e.g., based on carbon content). These considerations may argue for instead relying on emissions allowances or GHG taxes (as described in the preceding section) as the primary funding source. Wires and pipes charges may nonetheless have certain practical advantages and could be imposed even in the absence of, or in advance of, mandatory GHG regulations. A related alternative is a so-called "check-off" program analogous to those that fund the agricultural commodity boards overseen by the Department of Agriculture (such boards exist for beef, pork, and dairy). Congress could direct the Federal Energy Regulatory Commission to impose a wires and pipes charge on certain types of fuels *if* the charge is passed by industry referendum. In 2002, for example, the American Gas Association proposed a check-off program for gas research. We discuss a related institutional option—"self-organizing industry boards"—in a later section on private research consortia.

RD&D Institutional Options

A range of institutional options exists for administering and performing energy RD&D in the public and private sectors. These options include government agencies (e.g., DOE, NSF, the Environmental Protection Agency, and the Department of Defense), private firms and consortia, universities, and other non-profit research institutions. We focus here primarily on the institutions most often considered in policy discussions concerning an expanded role for public funding of energy- or climate-related RD&D.

U.S. Department of Energy and the National Laboratories

The U.S. government has spent over $100 billion in real terms on energy R&D over the last three decades, mostly through DOE programs. This direct federal spending represented about a third of total national expenditures on energy R&D; the balance was spent by the private sector. The private-sector share of the total has fallen, however, over the last decade. DOE energy research has gone through several transitions over the last three decades, both in terms of its relative focus on precommercial basic research versus technology demonstration and in terms of the emphasis placed on different technology areas (e.g., nuclear power, fossil fuels, energy efficiency, and renewables). Along the way, the Department's research objectives have also shifted from addressing concerns related primarily to energy security and resource depletion to a greater emphasis on environmental issues.

While the energy independence goal of the Nixon administration's Project Independence quickly proved impractical, government policy with respect to energy R&D stressed the development of alternative liquid fuels well into the 1980s. This emphasis culminated in the creation of the Synthetic Fuels Corporation (SFC) in 1980 which became emblematic of the large, expensive demonstration projects undertaken during this era. The following year, the incoming Reagan administration dramatically changed the direction of national energy policy and federal research goals began to stress long-term, pre-competitive R&D and lower overall budgets. The1980s were mostly a time of retrenchment for

DOE's research program, although funding levels stabilized in the late 1980s and early 1990s. Congressional appropriations also began to emphasize environmental goals at that time, with large expenditures for the Clean Coal Technology demonstration program.

The shift to a greater emphasis on environmental goals, energy efficiency and renewable energy, public-private partnerships, and cost-sharing continued over the course of the Clinton administration in the 1990s. Federal support for basic energy research has received the most consistent funding since the late 1980s, including in recent years. Nonetheless, interest in large-scale, government-sponsored demonstration projects has continued: a recent example is the FutureGen Initiative, which seeks to demonstrate zero-emissions technologies for producing hydrogen and electricity from coal. Interestingly, the debate around FutureGen has highlighted some of the conflicting viewpoints that exist regarding the proper orientation of federal energy RD&D. On the one hand, some are concerned that the project represents too much public involvement in a large demonstration project; on the other hand, FutureGen has been criticized for being too oriented toward longer-term research and not enough toward near-term commercialization. This is in part related to funding requirements for the project, which demand a lower cost-share for private-sector participants than would otherwise be typical because the project is classified as research.

A number of studies over the last several years have evaluated the performance of federal energy R&D programs.[3] Although these programs have produced some notable failures and although their performance has varied widely, the literature typically finds that federal energy R&D investments have, on the whole, yielded substantial direct economic benefits as well as external benefits such as pollution mitigation and knowledge creation. Government-sponsored energy R&D programs are also commonly thought to have improved substantially since the 1970s and early 1980s, both in terms of the way they are managed and in terms of the objectives they target. On balance, available studies suggest that federal intervention is most appropriate for R&D activities that are unlikely to be adequately funded by private industry. Moreover, these studies tend to find that the optimal federal energy R&D portfolio is balanced, flexible, and incorporates both basic and applied research, with successes offsetting unanticipated failures. Private-industry involvement is almost always mentioned as being very important, particularly as technology reaches the commercialization stage; greater international cooperation is also desirable. Typically, stronger leadership, targeted spending, rigorous oversight, and clear goals and benchmarks are recommended as measures that can facilitate project success and help to minimize wasteful expenditures.

At present, the federal government sponsors RD&D on GHG-reducing technologies primarily through the approximately $3 billion in DOE-funded grants and contracts that are awarded annually to national labs, universities, and industry for energy-related research. This research support is administered largely by the DOE Office of Science and the DOE program offices: Energy Efficiency and Renewable Energy (EERE), Fossil Energy (FE), and Nuclear Energy (see DOE organizational chart at http://www.energy.gov/organization/orgchart.htm). The NSF and other federal agencies also fund research relevant to energy and climate-mitigation technology, but these efforts tend to be on a smaller scale and focused more on basic science. Federal grants and contracts fund both research centers and individual projects, and are often awarded through a competitive process involving a request for proposals, proposal review, and selection.

Within DOE, the Office of Science focuses on basic research, while the program offices focus almost entirely on applied research and development. In the United States, the DOE Office of Science is the largest single supporter of basic research in the physical sciences, accounting for 40 percent of federal outlays in this area. The Office of Science makes extensive use of peer review and federal advisory committees to develop general directions for research investment, help identify priorities, and determine which scientific proposals to support. Tables 1 and 2 show how much funding DOE directed to specific research areas in FY2006 and how this funding was distributed to different entities engaged in energy R&D.[4] Note that the acronym FFRDC in these tables stands for "federally funded research and development center."

Of the 37 currently active FFRDCs, DOE sponsors 16—more than any other agency.[5] Otherwise known as the national labs, these 16 FFRDCs perform about two-thirds of DOE-funded energy R&D and receive about 95 percent of their funding from the federal government. FFRDCs administered by universities and other non-profit entities receive the majority of funding, with the remainder going to industry-run

3 National Research Council. 2001. *Energy Research at DOE: Was it Worth It?* Washington, DC: National Academies Press. Also see: J. Chow and R.G. Newell. 2004. A Retrospective Review of Energy R&D. Washington, DC: Resources for the Future.

4 Based on $4.5 billion in R&D spending by the DOE program offices and Office of Science (which also supports non-energy related research). Source: National Science Foundation. 2007. *Federal Funds for Research and Development: Fiscal Years 2004–06.* Arlington, VA: NSF.

5 See http://www.nsf.gov/statistics/nsf06316/ for a master list of all FFRDCs.

Table 1 U.S. DOE RD&D Spending (FY 2006)

Office	Total	Intramural	FFRDCs			Industry	Universities	Nonprofits
			Industry	University	Nonprofit			
Energy Efficiency and Renewable Energy	**100%**	**37%**	**7%**	**9%**	**35%**	**—**	**10%**	**3%**
Basic Research	3%	1%	1%	—	1%	—	—	—
Applied Research	41%	16%	4%	4%	12%	—	4%	1%
Development	50%	20%	2%	5%	18%	—	5%	1%
R&D Plant	5%	—	—	—	5%	—	—	—
Fossil Energy	**100%**	**23%**	**1%**	**4%**	**5%**	**52%**	**10%**	**5%**
Basic Research	2%	—	—	—	—	—	2%	
Applied Research	43%	6%	1%	1%	1%	24%	8%	1%
Development	55%	17%	—	3%	4%	28%		4%
Nuclear Energy	**100%**	**—**	**24%**	**16%**	**36%**	**7%**	**13%**	**—**
Applied Research	99%	—	24%	16%	35%	7%	13%	—
Development	1%	—	—	—	1%	—	—	—
Office of Science	**100%**	**2%**	**2%**	**49%**	**25%**	**4%**	**17%**	**1%**
Basic Research	84%	2%	2%	39%	20%	4%	17%	1%
R&D Plant	16%	—	—	10%	5%	—	—	—
TOTAL	**100%**	**9%**	**4%**	**37%**	**25%**	**9%**	**15%**	**2%**

Table 2 U.S. DOE RD&D Spending (FY 2006) ($ millions)

Office	Total	Intramural	FFRDCs			Industry	Universities	Nonprofits
			Industry	University	Nonprofit			
Energy Efficiency and Renewable Energy	**645**	**238**	**43**	**58**	**226**	**—**	**63**	**17**
Basic Research	22	9	4	2	4	—	2	1
Applied Research	264	103	26	24	76	—	27	7
Development	325	127	12	30	113	—	33	9
R&D Plant	35	—	1	2	32	—	—	—
Fossil Energy	**478**	**110**	**5**	**21**	**22**	**250**	**45**	**24**
Basic Research	9	0					9	—
Applied Research	204	30	5	5	5	114	37	7
Development	264	80	—	15	17	135	—	17
R&D Plant	1	—	—	—	—	1	—	—
Nuclear Energy	**249**	**3**	**61**	**39**	**89**	**17**	**33**	**7**
Applied Research	248	3	61	39	87	17	33	7
Development	2	0	—	—	—	—	—	—
Office of Science	**3,183**	**57**	**62**	**1,560**	**810**	**130**	**538**	**26**
Basic Research	2,681	57	52	1,239	645	128	535	25
R&D Plant	502	—	10	321	166	2	3	1
TOTAL	**4,555**	**409**	**171**	**1,678**	**1,147**	**396**	**679**	**75**

FFRDCs, industry, universities, and other non-profit research organizations. The main DOE labs focused on energy science and technology are the university-administered Ames, Argonne, Lawrence Berkeley, and Fermi labs; the industry-administered Idaho lab; the non-profit administered National Renewable Energy, Oak Ridge, and Pacific Northwest National labs; and the DOE-administered National Energy Technology Laboratory. All are overseen by the DOE Office of Science, except for the National Renewable Energy Laboratory and the National Energy Technology Laboratory, which are overseen by the Department's EERE and FE program offices respectively.

U.S. National Science Foundation

The NSF's mission is to support all fields of science and engineering, except medicine. With a current annual budget of just under $6 billion, the NSF backs about 20 percent of all federally funded basic research performed at American universities and colleges. Unlike DOE, which maintains the network of national labs, the NSF funds all work directly through the researcher's home institution. A major focus of the NSF's current strategic plan is encouraging transformational and multidisciplinary fundamental research. In supporting basic research, the NSF provides funding in nascent areas of R&D where private firms typically do not wish to venture. The NSF also integrates education and training objectives in its funding decisions to help build human capacity to apply technological advances and conduct future research.

Although the NSF does not have a program specifically geared toward energy research, energy- and climate-related projects may be funded across several of its disciplinary categories. Almost 60 percent of FY2002 funding went to engineering, the physical sciences, and environmental sciences. Thus, for example, recent NSF grants have been awarded for research to improve storage technologies for solar energy, to study the use of bacteria to filter hydrogen gas, and to develop new engineering techniques to improve technologies that extract energy from ocean wave currents. Several of the NSF's strategic foci are also directly relevant to GHG mitigation, including advanced manufacturing technology, biotechnology, advanced materials and processing, civil infrastructure systems, and environmental research.

Advanced Research Projects Agency-Energy (ARPA-E)

The Defense Advanced Research Projects Agency (DARPA) has provided the inspiration for a number of proposals that would create an analogous agency focused on innovative energy technology research—"ARPA-E." A major motivation is the desire to provide an efficient institutional home for R&D that does not fit well within the existing DOE organizational "stovepipes." The 2005 National Academy of Sciences (NAS) report *Rising Above the Gathering Storm* included the following recommendations concerning a new ARPA-E:[6]

The director of ARPA-E would report to the [DOE] under secretary for science and would be charged with sponsoring specific research and development programs to meet the nation's long-term energy challenges. The new agency would support creative "out-of-the-box" transformational generic energy research that industry by itself cannot or will not support and in which risk may be high but success would provide dramatic benefits for the nation. This would accelerate the process by which knowledge obtained through research is transformed to create jobs and address environmental, energy, and security issues. ARPA-E would be based on the historically successful DARPA model and would be designed as a lean and agile organization with a great deal of independence that can start and stop targeted programs on the basis of performance and do so in a timely manner. The agency would itself perform no research or transitional effort but would fund such work conducted by universities, startups, established firms, and others. Its staff would turn over approximately every four years. Although the agency would be focused on specific energy issues, it is expected that its work (like that of DARPA or NIH) will have important spinoff benefits, including aiding in the education of the next generation of researchers. Funding for ARPA-E would start at $300 million the first year and increase to $1 billion per year over five or six years, at which point the program's effectiveness would be evaluated and any appropriate actions taken.

A House bill to create an ARPA-E (H.R. 364) was voted out of the Science Committee in June 2007 and sent to the full House. The House version would have established ARPA-E within DOE and defined its primary objective as follows: "to reduce the amount of energy the United States imports from foreign sources by 20 percent over the next ten years." H.R. 364 goes on to state that ARPA-E should accomplish this objective by "(1) promoting revolutionary changes in the critical technologies that would promote energy independence; (2) turning cutting-edge science and engineering into technologies for energy and environmental

6 Augustine, N., et al. 2006. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* Washington, DC: National Academies Press. Also see: Van Atta, R. 2006. *Energy and Climate Change Research and the DARPA Model.* Testimony before the House Committee on Government Reform, 109th Congress, 2nd Sess. Mowery, D. 2006. *Lessons from the history of federal R&D for an Energy ARPA.* Testimony to the House Committee on Science, 109th Congress, 2nd Sess.

application; and (3) accelerating innovation in energy and the environment for both traditional and alternative energy sources and in energy efficiency mechanisms to decrease the Nation's reliance on foreign energy sources." Authorized funding levels were similar to the recommendations in the *Gathering Storm* report and would be deposited in an energy independence acceleration fund within the U.S. Treasury to be used for awarding competitive grants and entering into cooperative agreements or contracts with academic institutions, companies, or consortia (including the national labs).

In April 2007, the Senate passed S. 761 (the America Competes Act), which among other things stated that "The Secretary [of Energy] shall establish an Advanced Research Projects Authority-Energy to overcome the long-term and high-risk technological barriers in the development of energy technologies." The legislation further provides for the Authority to have a director and an advisory board, requires the NAS to conduct two reviews of its actions, and authorizes appropriations "as necessary." The activities of the Authority are much less specifically defined than in the House ARPA-E bill (H.R. 364).

The House and Senate passed the America Competes Act in July 2007 (S. 761 and HR 2272, 110th), and in doing so adopted the less detailed ARPA-E language of S. 761. The Act was signed into law by President Bush in August 2007. Upon signing it, however, President Bush indicated he was "disappointed that the legislation includes excessive authorizations and expansion of government…including a new Department of Energy agency to fund late-stage technology development more appropriately left to the private sector…." The President also indicated that he "will request funding in my 2009 Budget for those authorizations that support the focused priorities of the ACI [American Competitiveness Initiative], but will not propose excessive or duplicative funding based on authorizations in this bill." Presumably this means that the current administration will not be seeking appropriations for ARPA-E.

This position had been elaborated in more detail in an April 26, 2007 letter from the Secretary of Energy and Director of the Office of Science and Technology Policy, which stated: "At the same time that we support the conceptual goals of ARPA-E, we continue to have serious concerns about its potential implementation and its impact on ongoing DOE basic research efforts. Specifically, the Administration is strongly opposed to the creation of new bureaucracy at DOE that would drain resources from priority basic research efforts." The letter goes on to express "serious doubts about the applicability of the national defense model to the energy sector" and a concern that the new agency should "not result in the establishment of an additional layer of bureaucracy or hinder the ongoing support for advanced research now underway in these offices. Similarly, we also urge that this legislation not shift DOE's current balance of efforts along the spectrum of research and development."

In concept, ARPA-E was initially intended to have some of the same flexibilities that DARPA has in hiring staff, contracting, and managing research. Proponents argued that ARPA-E would encourage project managers to pursue risky projects with the potential for more revolutionary discoveries by providing proper isolation from the pressure to deliver short-term results along with intense scrutiny of project failures. This approach was intended to complement the traditional "stovepipe" structure of the DOE program offices, which might otherwise limit the pool of resources available for non traditional areas of R&D. Proponents also tended to argue that the agency would need strong support from the Secretary of Energy and President. It remains to be seen, however, whether an energy version of DARPA would receive the simple oversight and strong backing in Congress that DARPA itself has enjoyed for years. Unlike DARPA, which has natural and closely linked funder, customer, and end-user in the Defense Department, ARPA-E would have no comparable "lead purchaser." Now that it has been established (at least on paper), the question remains what such an agency would accomplish in practice. Even without a mission that is clearly distinct from the broader DOE mission, an ARPA-E with its own director, advisory board, and potentially its own budget, could potentially serve a distinct purpose within DOE.

Government and Quasi-Government Corporations

A number of recent proposals have sought, through federal legislation, to establish non-profit corporations that would focus on low-carbon energy RD&D. In this section we briefly describe some of these proposals, which have emerged as part of a larger movement over the last several decades toward the establishment of government and quasi-government organizations that have both public- and private-sector characteristics.[7] Supporters of these types of organizations see them as a way to introduce a more entrepreneurial style of management to publicly funded

7 Kosar, K.R. 2007. *The Quasi-Government: Hybrid Organizations with Both Government and Private Sector Legal Characteristics.* CRS Report for Congress RL30533. Washington, DC: Congressional Research Service. The report discusses several categories of quasi-governmental entities, including: (1) quasi-official agencies, (2) government-sponsored enterprises (GSE), (3) federally funded research and development corporations, (4) agency-related nonprofit organizations, (5) venture capital funds, (6) congressionally chartered nonprofit organizations, and (7) instrumentalities of indeterminate character.

RD&D, with an attendant focus on outputs and results rather than conformance to process. In such organizations, so the argument goes, risk-taking by managers to improve performance would be more accepted and encouraged. Government-established corporations typically also have greater autonomy and flexibility than federal agencies in terms of hiring, salaries, and interactions with the private sector, and in terms of how they operate under budget and regulatory constraints. The ability to act as the recipient of a dedicated revenue stream that is outside the normal appropriations process is also appealing to some. Greater insulation from political influences is frequently mentioned among the advantages of quasi-governmental corporations, although it is not clear how much difference would exist in practice between the pressures experienced by government agencies versus quasi-government corporations.

On the other hand, critics tend to view hybrid public-private organizations as weakening the government's capacity to perform its responsibilities and contributing to an erosion of the protections afforded by due process, governmental checks and balances, and political accountability. They view the attraction of quasi-governmental organizations as reflecting the natural tendency of organizational leaders—whether they operate in the public or private sphere—to maximize autonomy in policy and operations. In government, however, this natural tendency is typically held in check by strong counter forces based on laws and accountability structures. A challenge therefore arises in harnessing the potential power of corporate-based structures to achieve efficient outcomes while also satisfying the need for public accountability.

Federal charters to establish a corporation typically have the following elements: (1) name; (2) purpose; (3) duration of existence; (4) governance structure (e.g., executives, composition of the board); (5) powers of the corporation; and (6) federal oversight powers.[8] These elements each have detailed sub-elements, a discussion of which is beyond the scope of this issue brief. The act that established the Synthetic Fuels Corporation, for example, was about 80 pages long, not including a lengthy explanatory conference report. Other charters are, however, much shorter. Governance structures will affect whether a given corporation is subject to the Administrative Procedures Act, potential auditing by the General Accountability Office, and the Freedom of Information Act; they will also affect the degree to which a corporation is subject to specific provisions of the Government Corporation Control Act regarding budgeting, financial accounting and auditing, management reporting, security holdings, and debt obligations.

Energy Technology Corporation

An energy technology corporation (ETC) would be a new, quasi-governmental corporation intended to provide incentives for precommercial research. This idea represents the application of a broader concept—the civilian technology corporation recommended in a 1992 NAS report—applied specifically to the energy sector.[9] The ETC would focus on developing technologies whose size, scope, or expected return falls outside what a private venture capital firm or other private-sector entity might fund. Some have suggested that an ETC would take certain structural elements of the Synthetic Fuel Corporation (SFC), but unlike that entity would encourage innovation through financial incentives and by "buying information" instead of setting production goals.[10] Important guiding principles that have been mentioned in connection with the ETC concept include cost-sharing, industry involvement in project initiation and design, insulation from political concerns, diversification of investments, openness to foreign firms, and program evaluation.

Specifically, proposals to establish an ETC typically call for a single appropriation (to insulate somewhat from political pressure) that would ideally be invested so that the returns could be used to fund loans, loan guarantees, production tax credits, purchase guarantees, and other instruments as appropriate. After a few years, the ETC would be subject to review and potential dissolution. Guided by an appointed board, the ETC would be independent from both the executive and legislative branches and hence would in part avoid the discontinuity and pressure of constituent-driven politics and appropriations. The ETC would also have flexibility in choosing investments and could interact with university consortia, industry, national labs, and other projects. Where cost-sharing is infeasible, the ETC could arrange equity venture agreements with small companies. Exemption from civil service requirements would allow it to offer compensation packages for highly-skilled staff that are competitive with the private sector. The modern ETC would also avoid the cumbersome procurement regulations that hampered the SFC.

Among various problems such a corporation would face, the ETC would be under pressure to show high rates of return,

8 See: Kosar, Kevin R. 2005. *Congressional or Federal Charters: Overview and Current Issues*. CRS Report for Congress RS22230. Washington, DC: Congressional Research Service.

9 National Academy of Sciences. 1992. *The Government Role in Civilian Technology: Building a New Alliance*. Chapter 3. Washington, DC: National Academies Press. Also see Deutch, J. 2005. What Should the Government Do To Encourage Technical Change in the Energy Sector? *MIT Joint Program on the Science and Policy of Global Change. Report No. 120*. Cambridge: MIT.

10 See Deutch (2005).

even though its portfolio would include high-risk investments that otherwise would not be funded given existing market incentives. In fact, a high rate of success might indicate that the ETC is straying toward technologies that are ready for commercialization instead of targeting the earlier, pre-commercial phases of the innovation process. Defining what does or does not constitute "pre-commercial" technology research could be controversial, of course; similarly, it could be difficult in practice to apply other bounds or guidelines to the corporation's involvement in specific aspects of the technology-innovation process.

Synthetic Fuels Corporation

The SFC was established in 1980 as an independent, wholly federally-owned corporation to help create a domestic synthetic fuel industry as an alternative to importing crude oil. Under political pressure to backstop international oil prices, the SFC established a production target of 500,000 barrels per day. It had a seven-member board of directors, one of whom was a full-time chairman, and all of whom were appointed by the President and confirmed by the Senate. The SFC had the authority to provide financial assistance through purchase agreements, price guarantees, loan guarantees, loans, and joint ventures for project modules. After predicting oil prices of $80–$100 per barrel and a synfuel price of $60 per barrel, the SFC was crippled when oil prices plummeted to below $20 per barrel. It was eventually canceled in 1986 after several billion dollars in expenditures. Many experts have criticized the SFC as an example of an inappropriate and failed intrusion of government into large-scale commercial demonstration, an area better left to the private sphere.[11]

Climate Change Credit Corporation

The Lieberman-McCain "Climate Stewardship and Innovation Act of 2007" (S. 280, 110th) proposes to establish a new entity called the Climate Change Credit Corporation (CCCC). The CCCC would be a nonprofit corporation; it would not issue stock and would not be considered "an agency or establishment of the United States Government." The CCCC would have a bi-partisan, five-person board of directors, one of whom would be chairman and all of whom would be appointed by the President and confirmed by the Senate. With respect to technology, the main purpose of the CCCC would be to act as the recipient of emissions allowances, which it would sell. The proceeds would then be transferred to a new Climate Technology Challenge Program (CTCP) within DOE. The CTCP in turn would award funding for "development, demonstration, and deployment of technologies that have the greatest potential for reducing greenhouse gas emissions" using a competitive process. In this structure, the flow of money from a non-governmental corporation to the DOE could present implementation problems. S. 280 would also establish a Climate Technology Financing Board within DOE to represent the federal government's interest in joint venture partnerships, loans, and loan guarantees with industry. As mentioned above, these purposes relate mainly to technology deployment rather than to RD&D.

11 See, for example: Cohen, Linda R. and Roger G. Noll. 1991. The Technology Pork Barrel. Washington, DC: Brookings.

Private Research Consortia

Private industry consortia represent another potential entity for administering and/or performing RD&D activities. Joint investment and collaboration can help internalize spillover benefits and reduce redundant research among firms, thereby increasing overall innovation, reducing costs, or both. There have been several examples of industry consortia since federal antitrust policy toward collaborative R&D was revised in the 1980s. In addition to securing funding, one of the main challenges for private consortia is finding areas for cooperative research that do not run afoul of the normal competitive interests of companies. Another issue for industry consortia engaged in alternative energy research is that a wide variety of fuels, technologies, and approaches are likely to be relevant for achieving GHG reductions. At a minimum this implies that no single consortium could address the full spectrum of energy- and climate-technology RD&D opportunities. This section describes several existing private-sector consortia that could play an expanded role in energy-technology innovation, particularly as coordinators and administrators of increased RD&D funding. Outside the energy sector, perhaps the best-known private consortium is SEMATECH, the Semiconductor Manufacturing Technology Consortium.

SEMATECH

Until 1996, SEMATECH was funded in equal amounts by industry and DARPA (its budget totaled about $200 million annually). SEMATECH's 2007 budget is $160 million. The original goal of this consortium was to perform pre-commercial mid-term research in a collaborative setting with the ultimate goal of reviving American competitiveness in the semiconductor industry. However, much of the research was done in highly proprietary areas, such as manufacturing processes. Hence, the focus of the consortium shifted toward encouraging R&D by firms that develop semiconductor manufacturing equipment. This allowed for the industry as a whole to benefit somewhat equally from SEMATECH R&D.

The consortium has its own central research facility and draws upon constituent firms for technical staff. The direct employment of assignees eases technology transfer back to the member firms.[12]

Electric Power Research Institute

The Electric Power Research Institute (EPRI) was established as a nonprofit organization in 1973 in response to government pressure following a major blackout that struck the Northeast region in 1965.[13] It was charged with managing a national R&D program for the electric power industry. EPRI was initially funded by a fee levied on member firms based on their size. Member firms that paid fees had access to all R&D results and could serve on various committees within the organization. EPRI is well established in the electric power industry: its members currently generate over 90 percent of U.S. electricity. EPRI acts as a funding clearinghouse through which project leaders select engineers and scientists to perform R&D. Rather than operate a major centralized laboratory, the Institute funds external research.

EPRI has been an effective vehicle for wide-ranging collaborative research, but deregulation in the 1990s caused its revenues to decline to $285 million in 2006 after peaking at over $600 million in 1994 (EPRI 2006 Annual Financial Report). The organization has adapted by changing its decision-making and funding structures. In the past, EPRI's Board of Directors and Research Advisory Committee (RAC) reviewed projects along with organizational goals and priorities during an annual joint meeting. Now that many member companies find themselves in direct competition, they have the option to buy into various *a la carte* projects presented by the Board. A small portion of the resulting funds is funneled back to EPRI's Office of Innovation to fund long-term, potentially revolutionary research. About 25 percent of EPRI funds go into deployment projects. Overall, about 90 percent of project funds go directly to technology RD&D, while 10 percent of funds are spent on economic and industry analyses.

United States Council for Automotive Research

Beginning in the 1980s, U.S. automakers began collaborating on technology initiatives. Facing increased competition from foreign automakers (and taking advantage of new freedom from antitrust laws), Chrysler, Ford, and General Motors developed several research consortia. It became clear that an umbrella organization was needed to coordinate these efforts and, in 1992, the United States Council for Automotive Research (USCAR) was founded for just that purpose.
Over the past decade, consortia overseen by USCAR have addressed diverse automotive technologies, such as new batteries and light materials for fuel-efficient vehicles. In 2003, USCAR joined the U.S. DOE and five major energy corporations to form the FreedomCAR & Fuel Partnership, which was created to focus on the transition to a hydrogen economy. Prior to this, many of the same entities participated in the Partnership for a New Generation of Vehicles, which was aimed at building a car that could travel up to 80 miles on a gallon of gasoline while offering a competitive level of performance, utility, and cost to own. USCAR now oversees more than 30 consortia, teams, and working groups. Most of these consortia use existing research facilities and research funds. Technical experts are generally on loan from the participating automakers or from other involved organizations. USCAR partners with DOE on many projects and uses DOE's network of national laboratories. One concern that has been raised about USCAR, however, is that it gives a limited set of companies preferential access to public resources.

Gas Technology Institute

The Gas Technology Institute (GTI), formerly known as the Gas Research Institute, is a consortium that involves all three segments of the gas industry: production, pipelines, and distribution. Though it began as a funding hub for outside research, the GTI now maintains 29 research and test facilities. Until recently, it was funded by a surcharge on natural gas transported through interstate pipelines. In 1998, a Federal Energy Regulatory Commission settlement required the GTI to phase out this surcharge and move to voluntary funding by 2004. This development has dramatically reduced the organization's budget: its funding in 2006 totaled approximately $50 million, compared to budgets in the late 1980s and early 1990s that consistently totaled around $200 million. GTI's longer-term research is now funded by royalties from the technologies it develops and by voluntary contributions from a subset of "sustaining members"—these contributions total about $2 million annually. Sustaining members have access to all foundational R&D being done within the long-term research program.

Self-Organizing Industry Boards

One proposed variation on traditional research consortia (such as EPRI or SEMATECH) is the self-organizing industry board (SOIB).[14] This approach also has some features in common with the "check-off" programs that fund the

12 See: Grindley, P., D.C. Mowery, and B. Silverman. 1994. SEMATECH and Collaborative Research: Lessons in the Design of High-Technology Consortia. Journal of Policy Analysis and Management 13(4):723-758.
13 See Appendix G in National Academy of Sciences. 1999. *Decision Making in the U.S. Department of Energy's Environmental Management Office of Science and Technology*. Washington, DC: National Academies Press.

14 Romer, P. and Z. Griliches. 1993. Implementing a National Technology Strategy with Self-Organizing Industry Boards. *Brookings Papers on Economic Actvity: Microeconomics* 2:345-399.

agricultural commodity boards overseen by the Department of Agriculture. Under a SOIB-based research system, an industry would lobby the Secretary of Commerce or other responsible agency to find that collective action in support of RD&D would benefit the public. If the hearing is successful, the industry would hold a referendum to levy a tax or fee on the product or service it provides. The fee would be levied industry-wide, regardless of how an individual company voted. Though collection of this fee would be enforced by the government, revenues would not go to the Treasury. Firms within each industry would set up a series of boards dedicated to R&D; for example, a SOIB might support relevant university research or R&D investments by upstream industries. Each firm could contribute the fees collected from its customers to the board of its choice; if a suitable board did not exist, firms could establish one to their liking.

A major advantage of the SOIB approach is that it harnesses the public tax system to share the cost of high-spillover R&D without being paralyzed by the vagaries of Congressional oversight and appropriations. Moreover, it relies on the power of competition to direct funds into projects. Instead of having to respond to political pressure, firms can funnel money to the RD&D areas they feel would be most productive for the industry. The ability of new SOIBs to be created and compete with existing SOIBs helps ensure against research organizations becoming complacent and entrenched.

RD&D Policy Instruments: Contracts and Grants, Tax Credits, and Prizes

Alongside a system of patents and intellectual property rights, three primary mechanisms exist for encouraging R&D: research contracts and grants, research tax credits for the private sector, and innovation inducement prizes. In addition, important roles exist—within the public and private sectors—for coordination, planning, and road mapping of R&D activities; international cooperation; and general funding for national-level capacity building, including support for university-based science and engineering research and education infrastructure.

Contracts and Grants

Contracts and grants issued by DOE and NSF for research performed at the national labs or by universities, other non-profit institutions, and private firms represent by far the most important policy mechanism currently used to deliver federal support for energy RD&D. The government also funds demonstration projects to test and learn about the integration, reliability, and performance of GHG-reducing technologies that may not find adequate private funding otherwise. Demonstration projects (such as the ongoing FutureGen initiative) are typically designed and coordinated in partnership with the private sector at a scale that is closer to what would be employed in wider commercial deployment. The discussion of U.S. DOE programs elsewhere in this issue brief provides further elaboration on the level and allocation of this type of funding.

Tax Incentives for Private R&D

The Internal Revenue Code provides for two types of R&D tax incentives—tax credits and expensing. Both apply generally, though not solely, to energy- or climate-related R&D and both give firms incentives to expand research beyond what they would otherwise undertake by reducing the after-tax cost of R&D investments. Section 41 of the tax code allows firms to claim tax credits for extra expenditures on energy research and exploration while Section 174 provides for an expensing exception, whereby the taxpayer may treat research and exploration expenditures as current expenses, rather than charging them to a capital account that would be amortized only over a longer period of time.

The tax credit provided under Section 41 amounts to 20 percent of qualified research expenditures beyond a firm's baseline level (based on historical research expenditures or an alternative method). Qualified expenses include in-house salaries and supplies, certain time-sharing costs for computer use, and contract research performed by certain non-profit research organizations; moreover, these expenses must be incurred in the process of discovering new information that the taxpayer could use to develop new products or processes. A 20-percent credit with a separate threshold for payments is available for funds provided to universities for basic research; similarly, payments to certain energy research consortia (such as EPRI) are eligible for a 20-percent credit with no threshold. The U.S. Treasury estimates that the cost of these tax incentives has averaged about $5 billion each in recent years. Overall, econometric studies have found that they are effective in the sense that private sector research spending has increased roughly one-for-one with each dollar of tax credit extended. R&D tax credits have the advantage of encouraging private efforts to advance technology while leaving specific R&D decisions and judgments about the most productive areas for investment, given both economic and regulatory incentives, to industry. As a result, there is less need for policy intervention in the market and for government to "pick winners." Tax credits have other advantages over alternative R&D funding mechanisms: they create less of an administrative burden, obviate the need to target individual firms for assistance, and can be made permanent (and therefore not subject to annual appropriations).

Nonetheless, several factors have limited the overall impact of the research and exploration tax credit such that it represents only a small fraction of total federal and private-sector R&D expenditures. First, the credit was originally added to the tax code as a temporary measure—consequently, it has had to be renewed more than ten times, often with modifications. This uncertainty makes long-range research planning based on tax considerations difficult and has led many to call for making the research and exploration credit permanent. It has also proved difficult in practice to distinguish expenses that qualify for the credit from other expenses; moreover, under current rules, eligible expenditures are quite restricted. Even if research is considered qualified, related expenses such as overhead and equipment costs are not covered (although certain equipment costs are eligible for accelerated depreciation). Expenses for basic research conducted in-house and research conducted overseas are excluded altogether. Finally, tax credits are ineffective in situations where a firm has little taxable income. Thus the strength of the incentive they provide will vary with the business cycle.

Distributional considerations may also enter. One disadvantage of tax credits is that firms can claim them for research they would have undertaken even without additional incentives —in that case firms are rewarded at taxpayer expense without providing commensurate public benefit. To address this concern, tax credits are typically offered only for expenses above a defined baseline level, but in practice the true baseline level is impossible to determine. In addition, the fact that the vast share of credits tends to be claimed by large firms may raise equity concerns, although this result is somewhat to be expected given that large firms conduct most of the research.

In the context of climate policy, the main shortcoming of a tax credit approach is the difficulty of targeting R&D efforts that are particularly relevant to GHG mitigation. A recent modification of the existing credit to include contributions to energy research consortia addresses this issue to some extent. In addition, some groups (such as the National Commission on Energy Policy) have recommended that tax credits be increased for technologies aimed at improving end-use efficiency or otherwise reducing GHG emissions. It may be difficult, however, for Congress and the Treasury to develop workable qualification rules for an augmented R&D tax credit that would focus specifically on efforts relevant for GHG mitigation while excluding other types of R&D. This approach is also vulnerable to a broader concern that attempts to achieve particular policy goals by fine-tuning the tax code can create significant windfall opportunities for interest groups, distort market incentives, and result in bad tax policy.

Innovation Inducement Prizes

Recently, attention has turned to innovation-inducement prizes or awards as another possible mechanism for delivering R&D incentives. The idea would be to offer financial or other rewards for achieving specific technology objectives that have been specified in advance (in contrast to ex-post awards like the Nobel Prize).[15] Inducement prizes have historically played a role in advancing technology in areas ranging from maritime navigation and canning to mathematics, commercial aviation, and automotive engineering. Recent examples relevant to energy and climate policy include the Hydrogen Prize Act (which passed the House in the 109th Congress), a number of energy prizes authorized in the Energy Policy Act of 2005 (these have yet to be funded, however), Congressional interest in prizes to be administered by the NSF, the privately-funded Automotive X-Prize, and the Earth Challenge Prize announced by British financier Richard Branson. The prize approach has also been explicitly endorsed in some proposals as an instrument to be used by ARPA-E.

Inducement prizes are clearly not suited to all research objectives, but they have the potential to play a larger role along with research contracts, grants, and R&D tax credits. In contrast to these other instruments, prizes have the attractive incentive property of targeting and rewarding innovation outputs, rather than inputs: the prize is paid only if the objective is attained. Prizes or awards can help to focus efforts on specific high-priority objectives, without specifying how the goal is to be accomplished; potentially, they can also attract a more diverse range of innovators. A National Academy Committee recently endorsed the idea of establishing a program of innovation inducement prizes at NSF. This effort would be launched as an experimental program in close consultation with the academic and non-profit community, technical societies, and industry.[16]

15 Newell, R.G. and N. Wilson. 2005. Technology Prizes for Climate Mitigation. RFF Discussion Paper 05-33. Washington, DC: RFF.
16 National Research Council. 2007. *Innovation Inducement Prizes at the National Science Foundation*. Washington, DC: National Academies Press.