Technology Policies to Address Climate Change

This brief presents public policy tools available to provide support for research, development, demonstration, and deployment (RDD&D) of technologies that reduce greenhouse gas emissions. An emissions price induced by a cap-and-trade program can provide an incentive to "pull" new technology into the marketplace, while public funding for technology can provide a "push" with the two approaches more powerful in tandem than either alone. Economic theory provides the rationale for public expenditure on RDD&D, which can compensate for several market failures that would otherwise generate sub-optimal investments from the private sector. The appropriate policy tool depends on the stage of development for a particular technology and the scale of a project. Direct public expenditures, channeled through organizations such as the Department of Energy or the National Science Foundation, have a long history of funding earlier stages of research and development, and make up the bulk of current technology dollars. Some technologies to address climate change, such as next-generation nuclear power and carbon capture and storage, require a larger investment for early projects than private industry is likely to make, and could benefit from public funding of demonstration projects. The federal government can also provide inducements for private industry to invest in RDD&D with mechanisms such as investment tax credits. Indirect policies that can support technology deployment include standards that require a minimum performance or a market share requirement, and programs that identify and certify top efficiency performers in the marketplace. Funding sources for technology programs include appropriations from general revenues and dedicated revenues, perhaps from climate- or energy-related sources such as allowance auctions or dedicated energy taxes. Regardless of the source, funding must flow through and to multiple institutions that manage, select, and perform the actual RDD&D options. Each institutional option has strengths and weaknesses.

Addressing the challenge of climate change will require a technological transformation. The world's climate is warming rapidly, and it is very likely that most of the observed increase in temperatures is due to anthropogenic greenhouse gas (GHG) emissions.[1] Global GHG emissions must be reduced to 50-85 percent below 2000 levels by 2050 to stabilize atmospheric GHG concentrations at levels low enough to avoid severe risks to millions of people globally,[2] and U.S. legislation introduced in the 110th Congress has suggested reductions in a similar range.[3] Emissions are dominated by the carbon dioxide (CO_2) released during fossil fuel use, primarily for global energy production, which generates 56 percent of global GHG emissions; additional GHG emissions come from deforestation and land use change (17 percent), methane from agriculture, waste, and energy systems (14 percent), and nitrous oxide primarily from agriculture (8 percent).[4] Because energy and agriculture are central to most of the world's economic activity, mitigating global climate change while maintaining economic growth will require technologies that: 1) produce energy, crops, and forest products with minimal GHG emissions, and 2) use these basic inputs more efficiently.

Existing technologies, if they can be deployed widely, will be able to make a material contribution to reducing emissions. For example, researchers have proposed that substantially scaling up the deployment of a subset of existing technologies (such as fuel-efficient vehicles,

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Support for this series was made possible through a generous grant from the Doris Duke Charitable Foundation

carbon capture and sequestration, nuclear power generation, and conservation tillage) could allow stabilization of global emissions between now and 2050.[5] Additional technologies, including those not ready for commercialization and those yet to be invented, will be necessary to reduce long-term emissions significantly over the long term. No single technological "silver bullet" will be sufficient. A broad spectrum of technologies will reduce the economic costs of meeting energy and raw material needs in a carbon-constrained world, and will reduce the impact should any particular technology fail to deliver as expected.

There is no single technology that can deliver all the GHG reductions needed to protect the climate.

There is wide agreement that additional public support for technology RDD&D is an important part of domestic climate change policy. For example, the U.S. Climate Action Partnership (USCAP)—a group of leading companies and non-governmental organizations—has called for an "aggressive" technology program as a complement to a cap-and-trade system.[6] Though differing in the details, both of the major party 2008 Presidential nominees have advocated a cap-and-trade program, accompanied by an array of federal technology policies to address climate change.[7] The exact scale of the needed investment is currently being explored. One proposal from the Apollo Alliance—a coalition of environmental groups, labor unions, renewable energy firms, and financial services firms—advocates a "doubling of the national investment in clean energy research and development."[8]

To reach the point at which low carbon technologies are fully integrated into society, government needs to: 1) send an economy-wide price signal on GHG emissions, such as would be created by a cap-and-trade program, and 2) encourage and/or fund research, development, demonstration, and deployment (RDD&D) of these technologies on a scale that considerably exceeds current practice. Box 1 provides a simple conceptual framework for thinking about the RDD&D process.

Box 1 *What is the Process of Technological Change?*

Technological change is generally conceptualized as progressing through several distinct phases in passing from the lab to the marketplace. This "technology pipeline" starts with initial research phases, often divided into basic and applied research.[9] *Development* takes the knowledge produced in research and systematically applies it towards the production of useful materials, devices, and systems or methods to meet specific requirements,[10] often culminating in prototypes. *Demonstration* projects aim to test the feasibility of developed technology at the commercial scale, but with relaxed requirements for economic returns. "Demonstration" as a distinct phase is usually only discussed in the context of large-scale, expensive technologies. The final phase takes a technology to widespread use, and is called either *deployment*[11] (in the concrete sense) or *diffusion*[12] of knowledge (in the more abstract sense). While reality is more complex than this conceptual framework—there are multiple feedback loops and iterations during the various stages of development—it is useful to frame the discussion using a consistent and well-understood vocabulary.

This Congressional Policy Brief focuses on this second need and how to achieve it. The brief first presents a few examples of emission abatement opportunities that might be available in particular sectors through enhanced technology development and deployment, and policies that could or are being used to achieve these goals. Following these examples is a more in-depth discussion of several aspects of technology policy more broadly, including the economic theory that justifies public expenditure, the policy tools that are available for supporting technology RDD&D, the ways these policies can be funded, and the institutions that can be involved in managing technology RDD&D funds and performing the actual research.

Key Technologies—Examples

There is no single technology that can deliver all the GHG reductions needed to protect the climate. Rather, key technologies at various stages of research, development, demonstration, and deployment exist in many sectors of the economy that could benefit from the support of public policy. This section details a few specific technologies and the policies that could be (or are being) used to support them, drawing from a range of economic sectors and stages of development. A more in-depth discussion of the range of available technology policy tools follows.

Energy Efficiency

Approximately 43 percent of the CO_2 emissions from fossil fuel combustion in the U.S. are the result of energy services such as lighting, appliances, and heating and cooling systems in commercial, industrial, and residential buildings. There is a vast potential for emission reductions simply by increasing energy efficiency. A recent study by McKinsey & Company finds that fully developed efficiency technologies could provide between 710 and 870 megatons of emissions annual abatement potential (in CO_2-equivalents) by 2030 *at negative costs*—saving money while reducing emissions.[13] Examples of these technologies include lighting retrofits; improved heating, ventilation, and air conditioning systems; building envelopes; higher performance appliances and electronic equipment; and use of advanced information and communication technologies to monitor and optimize energy use in buildings.

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The lack of market penetration of a number of efficiency technologies is due, in large degree, to persistent market barriers such as mismatches between who bears the cost of an option (the homebuilder, the landlord, the management company) versus who gains the benefit of lowered energy costs (the homeowner, the renter, the commercial tenant). In addition, there are likely to be transaction costs associated with the deployment of many of these efficiency technologies.

Several public policy solutions, including many available to the federal government, can help overcome these market barriers. One route to wider deployment of new lower carbon technologies is to reduce their price. Federal government procurement can help an early stage technology reach economies of scale that lower production costs; production credits can directly lower costs for manufacturers; and rebates or suspending sales or excise taxes can lower costs to consumers.

As a public policy, standards such as ENERGY STAR® and appliance efficiency labeling requirements help consumers better assess life-cycle energy costs at the time of initial purchase. The Energy Independence and Security Act of 2007 phases in efficiency standards for light bulbs that will require reductions in energy use of up to 35 percent by 2020 and sets standards for a range of other appliances and equipment. The cost of incorporating energy efficiency into new construction is typically a fraction of the cost of retrofits, so stringent efficiency standards in commercial and residential building codes can have large emissions-reduction paybacks throughout the long life of an asset.[14] While building codes are under the jurisdiction of state and local governments, the federal government has a role to play. For example, DOE has created a model energy efficiency building code that it encourages state and local governments to adopt.

Electric Power Generation

Thirty-four percent of U.S. GHG emissions in 2006 were from electricity generation. What's more, several technologies that could reduce fossil fuel use in the transportation sector (e.g., plug-in hybrid electric vehicles) will rely on a shift towards electricity as an energy carrier. A substantial shift towards low- and non-emitting power generation methods, including renewable wind and solar, nuclear, and fossil generation using carbon capture and sequestration would substantially reduce GHG emissions in the United States. In addition, advanced information and communication technologies create opportunities to improve the efficiency of transmission and distribution in the electric power grid.

Advanced renewable energy and advanced nuclear options are examples of technologies still in the early stages of research and development. Substantial funding of a broad range of basic and applied energy research in these areas will allow the United States to accelerate the rate at which such key technologies can be brought to market and widely deployed. Doing so may, in turn, dramatically reduce the costs of meeting emission targets.

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When it comes to coal, substantial supplies in the United States and strong political representation of states that produce and use coal virtually guarantee that coal will be part of the country's energy mix well into the future. While extracting the energy from coal necessarily produces CO_2, carbon capture and sequestration (CCS) technologies can prevent that CO_2 from entering the atmosphere by removing it from the waste stream and storing it underground in geological formations. Oil companies have experience injecting smaller quantities of CO_2 into the earth for the purpose of oil extraction, so the technologies exist—at least on a small scale. Although several hurdles remain to demonstrating and deploying CCS on a larger scale, these hurdles could potentially be overcome by public funding. Specifically, large demonstration projects are necessary to establish the viability of CCS by solving not only technological problems, but also establishing a path through regulatory requirements and liability concerns.

It is unlikely that any single company will be willing and able to shoulder all of the costs and risks of early demonstration projects. Thus public financing could be key to establishing CCS in the market, with required funding estimated in the range of $8-30 billion over the next 10 to 15 years.[15] Government support for CCS demonstration projects could take many forms, such as reimbursing private firms for some or all incremental costs of CCS at either new or old plants, using allowances from a cap-and-trade program, or sponsoring public-private partnerships that build entirely new plants with integrated CCS.[16] Regardless, the scale of the effort needed will require policies that are carefully designed and targeted to meet the deployment goals. (See the Pew Center Congressional Policy Brief, *Addressing Emissions from Coal Use in Power Generation,* for a more detailed discussion.)

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Transportation

The transportation sector is responsible for almost one third of U.S. GHG emissions. Technologies that can reduce these emissions are in various stages of development. Some are "off-the-shelf" technologies available today. For example, hybrid vehicles are proving increasingly popular with Americans. In addition, new information and communication technologies can reduce vehicles miles traveled by allowing tele-working and online shopping, as well as by increasing the logistical efficiency of industrial and commercial supply chains. Other technologies, such as the so-called "zero-emissions" hydrogen vehicle, require substantial research to be used in the future.

In the short term, policy options include performance standards focused on improving vehicle efficiency (e.g., CAFE mileage standards); rebates or tax credits for producers or consumers of efficient vehicle designs, such as hybrids; and government procurement of efficient vehicles to stimulate demand and reduce production costs.

In the short-to-medium term, increased market penetration of hybrid vehicles and the use of lower GHG intensity fuels, such as biodiesel and cellulosic ethanol, will play an important role. The Renewable Fuel Standard in the Energy Independence and Security Act of 2007 requires increased use of biofuels in the near term. In the medium- to longer-term, low carbon fuel policies should focus on creating an incentive for all potential low GHG emitting energy sources for transportation. To ensure aggregate emissions actually decrease, policymakers need to consider GHG reductions over the entire lifecycle of using a new fuel including production/extraction, processing, and combustion/use. Hybrids and plug-in hybrids will continue to play an important transition role.

In the long term, a shift away from gasoline-powered internal combustion engines to alternative technologies (e.g., electric and fuel cell vehicles) can dramatically reduce emissions from transportation. It is important, however, that electric vehicles draw electricity from cleaner sources, so that a shift to vehicles fueled by electricity would result in additional GHG reductions. Similarly, to recognize the environmental benefits, the hydrogen used in fuel cell vehicles needs to be generated with low or no emissions. For these vehicles to increase in market penetration, current technologies (such as battery storage and hydrogen fuel cells) would need to dramatically improve, and new technologies would be required to store and/or distribute clean energy to individual vehicles. Government research and development dollars could therefore target battery technology, hydrogen distribution networks, fuel cell technologies, and low or zero-emissions hydrogen production technology. Government procurement, battery/fuel cell guarantee programs, and tax incentives or rebates can also speed deployment. (See Pew Center Congressional Policy Brief, *Policies to Reduce Emissions from the Transportation Sector,* for additional discussion.)

Public Technology Policy and Market Failures

Policies that put a price on GHG emissions such as a cap-and-trade program provide critical signals to innovators by indicating the directions of future markets.[17] They drive innovation as the private sector seeks to create value by meeting demand with new lower emissions technologies; the pricing signal also incentivizes the more widespread diffusion of existing technologies. In both cases, economic incentives "pull" new technology into the market. Government policies and funding can also provide a "push" for research, development, and demonstration of new technologies, and can assist in their widespread deployment in the market.

Carbon pricing and technology policy are not substitutes but rather should be seen as complements. A given reduction of GHG emissions can be achieved more cost-effectively if both technology and emissions pricing policies are used together than if either policy is used alone.[18] If complementary to a cap-and-trade system, technology policies will tend to lower the price of emissions associated with a given cap level for covered entities. If used in conjunction with a GHG tax, technology policies can further reduce emissions at a given tax level.[19]

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Used in tandem with an emissions reduction policy, technology policies can provide a hedge against sub-optimal emission pricing. If the emission reduction policy is not aggressive enough and the price signal is low, market-driven private-sector investment may fall short of that needed over the long term.[20] Uncertainties in future GHG prices and public policy commitments have the same effect.[21] Accordingly, a technology policy that reduces the cost of (and hastens the spread of) emission reductions can offset to some degree these potential problems in the implementation of a mitigation policy.

Without government intervention, research and development investments often fall short of the optimal level that maximizes social net benefits. Economic theory provides a clear explanation of the market failures that lead to this under-investment in private research and development (R&D), even in the presence of an optimal emission price signal. Specifically, firms have difficulty in capturing all the benefits from their R&D investments even in the presence of strong intellectual property protection, so the total social return exceeds the firm's return. Because of this "spillover" effect, investments in R&D falls short of the optimal amount, justifying public support.[22]

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Beyond research and development, it is important to note that large demonstration projects ("first-of-kind" facilities) are especially unlikely to be funded privately, because such projects typically involve costs and risks too big for any one firm to tackle. Public funding spreads costs and technical, market, and regulatory risks more broadly.

Other market failures also impede technology deployment. A prime example is the "landlord-tenant" problem, in which the owner of a rental unit bears the costs of energy efficient capital investments while the tenant accrues the benefits of lower utility usage.[23] Another example is the installation of energy efficient equipment in homes or businesses. This would produce sufficient payback through energy savings to cover upfront costs, yet is often not pursued because the builder will not purchase new, more expensive technology.

In addition to these market failures, deployment is often slow because the energy sector exhibits a high degree of inertia due to long capital investment cycles for production facilities and due to inflexible distribution systems. These structural barriers to deployment of new low carbon technologies would remain even if carbon pricing makes lower carbon options marginally cheaper.[24] Deployment policies can help cross these barriers, for example, by providing funds for early retirement of carbon-intensive capital or for the establishment of new distribution systems.

These three key points—that a carbon price is necessary but not sufficient, that private R&D spending is typically sub-optimal due to spillover effects, and that additional barriers and market failures slow demonstration and deployment—all support the use of technology policy tools to help address climate change.

Policy Tools

The federal government has a long history of providing support for basic scientific and technical research. Accordingly, there exist well-developed policy instruments for funding and incentivizing research and development. Overcoming the barriers to technology demonstration and deployment, however, requires a broader portfolio of policy tools. R&D, by itself, is not enough: a balanced technology policy must also promote diffusion of knowledge and deployment of new technologies.[25] A variety of policy tools are available at every stage of the technology pipeline, with the most appropriate option depending on the developmental phase and the scale of the particular technology, and the institutional structures available to support RDD&D of that technology.

In outlining the available policy tools, it is useful to draw a distinction between those that involve direct expenditure of public funds on RDD&D, and those that induce technology RDD&D indirectly. Indirect policy tools, while not requiring direct government outlays, can still affect public finances. Tax credits, for example, reduce income to the public treasury and may be expensive from the government's standpoint, while the enactment of standards or strong patent protection would likely not be.

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A variety of instruments can be used in distributing direct funding for targeted RDD&D, including grants, contracts, reverse auctions, innovation prizes, and direct funding for large-scale demonstration projects. Direct government funding for education and training—especially in scientific and technological fields—may not be as targeted, but can be an important factor in long-term RDD&D capacity. A range of government polices can encourage RDD&D by private firms without funding it directly, including investment or tax credits or rebates, loan guarantees, and liability limits. Standards applied to particular markets, industries, or products can reduce emissions and/or emissions intensity. Finally, complementary policies such as labeling requirements, voluntary market transformation programs, and strong legal patent protection can also accelerate deployment of new technologies. These instruments are described in greater detail below, ranging from more direct to less direct policy tools.

Contracts and Grants

When it comes to climate change technology research, contracts and grants issued by the Departments of Energy and Agriculture and the National Science Foundation for research at a variety of institutions, are likely to be the most important delivery tool to channel federal dollars into technology research and development.

Innovation Inducement Prizes

Financial awards can be offered for achieving a specific technology objective, and these innovation inducement prizes are gaining attention as a mechanism for incentivizing research, development, and demonstration. Recent examples include the public Hydrogen Prize Act and the private Automotive X-Prize.[26] Prizes reward technology outputs rather than inputs, requiring innovators to take a technology all the way through to successful demonstration. They are most suited to very specific and well-defined high priority objectives.

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Demonstration Projects

The cost of building "first-of-a-kind" facilities often greatly exceeds the cost of similar facilities built later. This initial hurdle is especially difficult to overcome in the case of expensive, complex, and large units that take advantage of qualitatively different technologies than previous generations (e.g., a nuclear power reactor). Even though a major new project may be very promising, its size and scope may create costs and risks that are simply too high for any one firm to bear. In these cases, government support for large demonstration projects can be critical in bridging the gap from development of a technology to widespread, market-based deployment. Carbon capture and sequestration (CCS) is a prime example of a climate change technology that is unlikely to be commercially deployed until the first few large-scale projects have been successfully demonstrated.[27] However, expensive, large-scale federal projects have a mixed history of success (e.g., DOE's Synfuels Corporation), and should be subject to very close scrutiny before proceeding.

Education and Training

Technological innovation is supported indirectly through direct government support for education and training more broadly. This is especially true for graduate level education and for professional training in technical fields of science and engineering. Government support for students in these fields yields benefits primarily in basic research and development, both through academic research performed during the period of support, and by expanding the workforce for both public and private R&D upon program completion.
Some would argue that dramatically increased government funding for direct RDD&D without commensurate increases in support for education and training would result in inefficiencies as demand for workers exceeds supply, diverting some funding towards increased labor costs rather than increased research capacity.

Subsidies

A range of government subsidies to producers or users of new technology can be designed to speed technology deployment by creating financial rewards rather than the regulatory sanctions typical in enforcing standards. Subsidies can take a variety of forms:

- **Investment tax credits** to firms that bring a new technology to market can lower the upfront investment costs of producing a new type of equipment, and can be tied either to costs or to the production level. These policies work to increase supply of a new technology on the market.

- **Production tax credits** are subsidies granted for a particular type of electricity generation on a per-unit-of-production basis, making renewables such as wind more competitive against higher emission production methods (see Box 2 for a comparison of investment and production tax credits).

- To increase demand for a new technology, **tax credits or rebates** can be granted to purchasers as well as producers, reducing the cost differences between old and new technologies and making the lower emitting or more efficient new products relatively more attractive. For example, many states offer tax rebates to consumers who purchase high-efficiency appliances.

- **Government procurement**, including methods such as tendering and reverse auctions, are less direct subsidies that guarantee a buyer for the newly developed technology. The subsidy comes in two forms. First, risk is shifted from industry to government. For example, a government commitment to purchase reduces the manufacturer's risk that a market will not materialize for a product after it is developed.

Box 2 *Investment Tax Credits vs. Production Tax Credits*

The policy mechanisms used to encourage the deployment of low-emissions technologies can create winners and losers among different industries. A clear example of this is the differential impact of a choice between investment versus production credits on the solar and wind industries. The market for solar energy products such as photovoltaic panels, solar water heating, and solar power concentrators, includes a range of scales from industrial power generation to smaller commercial-scale and domestic installations. Wind power, on the other hand, is almost entirely produced at industrial scales by large companies. Both of these technologies are relatively young and could benefit further from reductions in production costs associated with additional economies of scale, so public policies such as tax credits to speed deployment are beneficial. However, the ideal form of these subsidies depends on the technology being deployed. Because wind farms are financed by large corporations with access to financial markets, the wind industry has preferred the long-term payback of production tax credits, which provide a return on every kilowatt produced, to make their power more competitive on the market. The biggest hurdle for smaller scale solar installations, however, is not the long-term return to the power generated (much of the return is in reduced bills for small producers, not in profits from selling the produced energy), but rather is the initial high cost of installing a system. In this case, an investment tax credit is a better instrument for the industry, lowering the price that producers of solar products have to charge their customers for the equipment.

Second, it is quite possible that a higher price will be paid by government as an early adopter of a new technology, thereby allowing later private sector buyers to enjoy a lower price.

- **Loan guarantees** also subsidize industry by shifting the risk of failure or default to the government and lowering the costs of capital for private firms below what would be available on the open market for an unproven but promising technology.[28]

- **Limiting legal liability** to the users of a new technology is another implicit subsidy from government, insulating parties from possible economic damages. This approach may be relevant for CCS technology, where a release of geologically sequestered CO_2 could potentially undo climate benefits and cause additional harm, giving rise to litigation against the technology developer.

Tax credits for private R&D are a long standing, popular, and relatively uncontroversial tool for government to encourage domestic development of new technologies. Many would argue that firms do a better job of selecting "technological winners." Providing tax credits encourages this effort. These credits, however, only reduce rather than fully eliminate the market inefficiencies discussed above such as the spillover effect. They also likely subsidize some R&D work that would be conducted even in the absence of the credit.

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Standards

Four types of standards are often discussed as technology policy options, and are used primarily to speed deployment of demonstrated technology:

- **Uniform technology standards** are the least flexible, specifying that every covered entity must install a particular technology. An example would be a mandate that all vehicles must be capable of running on ethanol. These types of standards can most directly address network effects (i.e., the so called chicken-and-egg problems with new vehicle fuels, where vehicle manufacturers seek certainty that alternate fuels will be widely available and fuel producers seek sufficient demand by virtue of substantial sales of alternatively-fueled vehicles). While easy to verify and enforce, uniform technology standards require the government to determine which technologies should be mandated (i.e., they "pick winners"). They can also create significant economic inefficiencies when an inflexible standard is applied to all entities irrespective of variations in compliance costs across firms.

- **Market share standards** (or portfolio standards) are usually directed at energy generators and applied across an entire industry with trading permitted between firms. Examples would be statewide renewable portfolio standards (e.g., X percent of electricity must come from technologies A, B, or C by year Y), or industry-wide portfolio standards (e.g., X percent of coal-fired plants must use CCS by year Y). These standards can be targeted to a particular technology or suite of technologies, but allow some market-based flexibility in compliance.

- **Emissions performance standards** specify an amount of carbon emissions per unit of output, imposed at the source (e.g., X pounds CO_2 per kilowatt hour of electricity generated or X grams of CO_2 emitted by one gallon of motor fuel). These carbon intensity standards move away from specifying a particular technology, leaving it up to the market to find the best way to meet the standard. If intensity standards are set based on the emissions performance of the best available technology, they will speed deployment of leading technologies and development of cheaper alternatives with comparable emissions intensities.

- **Energy efficiency standards** regulate energy use rather than emissions in the form of minimum efficiencies for particular products (e.g., X kilowatt hours of electricity used per cubic foot of refrigerator space) or for a suite of products from a company (e.g., CAFE mileage standards for automakers).

In comparing standards to subsidies, standards generally fix the technology deployment target while the costs remain unspecified, whereas subsidies address the costs but with no guarantee of deployment results. The costs of standards are typically borne by the firms and sector in question and/or passed on to customers, while the costs of subsidies are spread more widely across broad classes of taxpayers. For this reason, subsidies might be especially important to help smaller firms absorb innovations, while larger firms could more easily bear the costs of standards without assistance.

Additional Complementary Policies

One of the important market failures that can lead to under-investment in energy saving technologies is the lack of information available to consumers regarding the efficiency of particular appliances and the cost effectiveness of energy conservation measures. Several programs at the state and federal level exist to address this problem. For example, EPA's voluntary ENERGY STAR® program began in 1992 and seeks to encourage consumers to purchase more efficient products by identifying a performance threshold for various products and allowing producers to label products exceeding that threshold to carry the ENERGY STAR® label. Outreach and technical assistance programs exist at both the federal and state level, such as efforts to assist businesses and individuals conduct energy audits and efficiency upgrades. State regulators also require many utilities to run demand side management programs that can help deploy energy saving technologies to power customers.

Strong patent protection helps to minimize the effects of innovation spillover away from the developing firm, thus increasing the expected returns on prospective private R&D projects and making them more likely to be carried out. Protection can, however, also limit diffusion of a particular technology, or fragmentation of the market among competing technologies, thus increasing prices and slowing diffusion.

Funding Technology Policy

Technology policy focused on climate change could be funded through either appropriations from general revenue, or by dedicating a policy-relevant revenue source (such as proceeds from a cap-and-trade allowance auction, or from fees on carbon-intensive producers of electricity) to finance technology development.

Some believe that revenue sources should be separated from spending decisions, and using general revenue to fund RDD&D achieves this. However, use of general revenues has two main disadvantages. First, funding can be buffeted by the year-to-year Congressional appropriations process, reducing long-term predictability and thus potentially having a chilling effect on innovation given the multi-year RDD&D pipeline. Second, because of political pressures against new spending, there is a good chance that funding levels would be much less than the needed investment if coming from general revenues.

Technology policy focused on climate change could be funded through either appropriations from general revenue, or by dedicating a policy-relevant revenue source.

Dedicated revenues, such as the proceeds from allowance auctions or a dedicated tax (such as a "wires and pipes" charge), are somewhat more insulated from the budget process. In the case of allowance auction proceeds, careful structuring could even link the amount of RDD&D investment to success in policy goals. For example, if a carbon price ceiling (sometimes referred to as a "safety valve") is included in legislation, then hitting the ceiling would trigger the sale of allowances above the cap. If revenues from such a sale were used to fund further technology innovation, then the failure to meet short-term caps would automatically expand funding for future technologies, perhaps making long-term caps easier to meet.

A dedicated tax need not be linked to an emission reduction program, leading some observers to argue that it could be simpler to manage and faster to implement. For example, H.R. 6248, the Carbon Capture and Storage Early Deployment Act, was introduced in the 110th Congress, would have authorized a per-kilowatt-hour assessment on the users of fossil-fuel generated electricity. Funds would flow through a non-governmental corporation, and would be dedicated to accelerating CCS deployment.

Irrespective of whether it is coupled with emission reduction policies or is adopted on a "stand alone" basis, a dedicated funding source might not ramp up as quickly as needed (e.g., if the proportion of allowances that are auctioned starts too low), might not be politically tenable (e.g., "no new taxes"), or may not match the needed amount or capacity for RDD&D activities.

Institutions for Managing and Executing Technology RDD&D

A variety of public, private, and academic institutions are potential candidates for distributing funds for technology RDD&D, and for performing the activities directly. Some institutions only disburse federal technology dollars, some only do research or program work, and others do both—so are all included here. Each of these institutions has its own strengths and limitations, and they are often partners, competitors, or even both simultaneously. This section gives a brief overview of the strengths and weaknesses of those institutions that are most likely to be players in climate change technology research.[29]

Department of Energy

The U.S. Department of Energy (DOE) engages in extensive R&D activities, managing grants to outside institutions, performing research intramurally, and tasking and managing research through a large network of national laboratories. DOE labs generally have high levels of expertise and excellent facilities. However, funding for DOE's advanced energy RDD&D programs has decreased by over 85 percent since its inception in 1978. While DOE R&D has generated both successes and failures, studies show that overall investments in energy technology traveling through DOE labs have yielded substantial direct economic benefits.[30] Most of the DOE labs do basic research, while only the National Energy Technology Laboratory and the National Renewable Energy Laboratory do industry-relevant applied research, respectively, in fossil energy and in renewables and efficiency. It is an open question as to whether this is the right balance to attain rapid diffusion of new technologies into the national energy infrastructure. There is also the danger that without a direct connection to the marketplace, federal intramural research might place too little emphasis on future commercialization potential; however DOE is well aware of this pitfall and has been actively addressing the problem through more partnerships with industry.

Some institutions only disburse federal technology dollars, some only do research or program work, and others do both.

Generally, DOE R&D programs are most likely to be successful at the earlier stages of the innovation process, including basic and applied research and development—but not as successful in demonstration and deployment.[31]

A New Research Entity: ARPA-E

Recent legislation authorized the establishment of a new research entity within DOE intended to translate the model of the DARPA program[32] to an energy research function. Congress authorized $300 million for ARPA-E in FY2008, but failed to appropriate funds to the project; the Administration has requested no funding for the program in FY2009. If this type of research model is to be successfully applied to energy research, ARPA-E will need substantial funding,[33] a clearly defined and well-accepted mission, autonomy, flexibility, and effective links with strong non-government research programs.

It can also be questioned whether a high-risk, high-return model such as DARPA is the right one. In general, DARPA works on projects at the behest of a single large client (i.e., the Defense Department) which is also the ultimate purchaser of new technologies that result from its work. The market for climate change technologies is much more heterogeneous. Such factors merit careful consideration in the design of ARPA-E.

Department of Agriculture

The USDA's Agricultural Research Service performs research and provides grants and contracts for outside research into technologies that can reduce emissions from agricultural and forestry sectors, as well as transportation through its work on biofuels.

National Science Foundation

NSF does not perform any in-house research, but a large amount of federal funding flows through it. These federal dollars are primarily directed at basic research and development, including a large amount of funding for universities.

Private Industry

R&D contracts with private firms have proven effective in some sectors, particularly in strongly "mission-based" agencies such as defense. Military aviation technology advancements have frequently been achieved through such arrangements. However, in the absence of a well-defined mission, such contracts can be hard to defend politically. Consortia of private industry players can avoid some of these dangers, can help reduce redundant research and distribute knowledge quickly among firms, and can ensure that clear technical objectives are defined. There are models of successful industry consortia, such as SEMATECH in the semiconductor sector, and EPRI in the electricity sector. However, there is a danger that consortia can tend toward least-common-denominator R&D if firms only agree on the most basic of goals or avoid supplying their best people to a joint project. Different approaches to working with private industry have advantages and disadvantages, and multiple approaches are likely important to include in a broad technology policy portfolio. Because of its inherent connections to the marketplace, industry research is most likely to be successful for applied research, development, and demonstration phases of the technology pipeline.[34]

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University Research

One of this country's greatest technological strengths is its university system and the well-established system of federal financing of university research through NSF and other agencies. Strong competition for federal research dollars, faculty, and graduate students helps maintain excellence. Studies show capacity for additional funding that could be managed by granting agencies as well as productively absorbed by the research community.[35] Technology dollars channeled through this route will also yield the important secondary benefits of education and training, and deployment can be assisted as graduates move into the work force. Because academic researchers typically conduct basic rather than applied research, however, the pool of academic expertise is smaller for applied R&D than for basic research. Accordingly, this funding route may be best suited for the earlier phases of the technology pipeline, and for those technologies whose environmental benefits might be farther in the future.

The scale of funding needed for RDD&D to meet the challenges of climate change far exceeds current government spending.

Other Collaboration

Additional institutional destinations for federal technology research dollars include quasi-government corporations and collaborations between two or more of the previously mentioned players. Collaborations across the above categories exhibit similar strengths and weaknesses as consortia of private industry players. Quasi-government entities can take on a range of legal structures[36] and are thought to benefit from a more entrepreneurial style of management, greater focus on outputs and results, and greater autonomy and flexibility than federal agencies or labs. Given the need for accountability when taxpayer resources are involved, however, complete freedom from direct government oversight is not feasible.

Lessons Learned

The development and deployment of a wide range of technologies will be necessary to reduce GHG emissions to levels that avoid dramatic climate changes. A wide range of federal technology policies can speed this transition in tandem with emission reduction policies like a cap-and-trade program. The two approaches together dramatically lower the overall costs of meeting emissions goals more than either approach alone. The scale of funding needed for RDD&D to meet the challenges of climate change far exceeds current government spending; ramping up quickly to this level of investment will require careful selection of appropriate policy options. While the above sections lay out details of particular technology policies, institutional options, and funding sources, a few cross-cutting principles drawn from previous technology programs can apply to any program:[37]

- A stable regulatory and market environment helps to minimize the risk and uncertainty faced by firms investing in new climate-friendly technologies. Effective RDD&D programs therefore require insulation from short-term political pressures.

- The results of the technology innovation process are inherently uncertain and difficult to predict. Programs must therefore support a broad suite of options rather than "picking winners," and policymakers must be prepared to tolerate some failures and learn from them.

This is not, however, an argument for disbursing public funds with no strings attached. Careful project selection, with meaningful input from multiple private-sector perspectives, can go a long way to ensure the commercial applicability of federally supported technologies. One approach is to blend top-down and bottom-up funding programs—supporting a subset of individual technologies that will have a large impact if successful, while also dedicating funding to broad research and development of new technologies with appropriate review mechanisms and decision criteria for allocating these funds.

- Technology policies work best if the policy is tailored to the stage of development of the particular technology. A wide range of technologies exist at various stages of development, so a range of appropriate polices are needed.

- While various deployment policies can help overcome real market failures, they also run the risk of going too far or running longer than is necessary, creating unnecessary subsidies over time.

While the emission reductions needed to avoid dramatic climate change seem daunting, they are well within reach if the United States provides leadership in promoting a range of new climate-friendly technologies.

Traditional American ingenuity supported with smart government policies can help tackle climate change.

Key Design Questions

- How much funding should be provided to support climate-related technology policies?

- What revenue sources should be used to support technology policies?

- Which institutions should manage the distribution of RDD&D funds, and what disbursement mechanisms should be used?

- Which institutions should perform the RDD&D activities? How should institutional arrangements vary throughout the technology development process?

- How can indirect policy instruments encourage private expenditures on RDD&D activities?

- How can policymakers determine the optimal portfolio of technologies to support? What is the correct balance between “picking winners” versus “throwing money at the problem”?

- Which funding mechanisms are appropriate for each sector, technology, and phase of development?

End Notes

[1] IPCC, *Fourth Assessment Report, Climate Change 2007: Synthesis Report, Summary for Policymakers,* 2007.

[2] IPCC, *Working Group III Contribution to the IPCC Fourth Assessment Report, Climate Change 2007: Mitigation of Climate Change, Summary for Policy Makers,* 2007.

[3] See the Pew Center on Global Change's Congressional Policy Brief, *Greenhouse Gas Emission Reduction Timetables* for a full discussion of needed emission reductions and the targets in particular legislative proposals.

[4] IPCC, *Working Group III,* 2007.

[5] Pacala, Stephen and Robert Socolow, Stabilization Wedges: Solving the Climate Problem for the next 50 Years with Current Technologies, *Science*, 305 968-972, 2004. Examples of wedges include doubling the expected fuel economy of cars in 2054 from 30 mpg to 60 mpg, or doubling the world's nuclear energy capacity as a substitute for coal power.

[6] United States Climate Action Partnership, *A Call for Action—Consensus Principles and Recommendations from the U.S. Climate Action Partnership*, January 2007, found at www.us-cap.org.

[7] For more information see the Pew Center on Global Climate Change's Voters' Guide to the Presidential Candidates and Climate Change found at www.pewclimate.org.

[8] See the New Apollo Program Full Report, *The New Apollo Program—Clean Energy, Good Jobs: An Economic Strategy for American Prosperity*, September 2008, found at www.apolloalliance.org.

[9] The National Science Foundation defines research as "systematic study directed toward fuller knowledge or understanding," divided into basic research directed toward the "fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind" while applied research is directed toward determining "the means by which a recognized and specific need may be met." See National Science Foundation, *Federal Research and Development Funding by Budget Function: Fiscal Years 2005-07*, 2007.

[10] National Science Foundation, 2007.

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[17] Alic et al., 2003.

[18] Goulder, Lawrence H., *Induced Technological Change and Climate Policy*, Pew Center on Global Climate Change, October 2004.

[19] Newell, Richard G., *Backgrounder: Climate Technology Deployment Policy*, Resources for the Future, October 2007.

[20] Newell, Richard G., *Backgrounder: Climate Technology Research, Development, and Demonstration: Funding Sources, Institutions, and Instruments,* Resources for the Future, September 2007.

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[22] Goulder, 2004.

[23] Newell, October 2007.

[24] Lempert, Robert J., Steven W. Popper, Susan A. Resetar, and Stuart L. Hart, *Capital Cycles And The Timing Of Climate Change Policy*, Pew Center on Global Climate Change, October 2002.

[25] Alic et al., 2003.

[26] H.R. 5143, the H-Prize Act of 2006, overwhelmingly passed the House but saw no action by the Senate. The bill would have provided $50 million over 10 years for prizes to be administered by DOE for parties that made important advancements at various stages of RDD&D of hydrogen as a fuel for vehicles. The Automotive X-Prize is a privately funded standing award of $10 million for the first team that can demonstrate a fully production ready 100 mile per gallon equivalent vehicle.

[27] Peña and Rubin, 2008.

[28] In the 2008 Omnibus Appropriations Act, Congress authorized $38.5 billion in loan guarantee authority to DOE for innovative energy projects, divided between nuclear power, renewables, and advanced coal.

[29] This section synthesizes ideas from Alic et al., especially from Table 1.I, and from Newell, October 2007.

[30] National Research Council, *Energy Research at DOE: Was it Worth It?*, National Academy Press, 2001.

[31] Alic et al., 2003.

[32] The Defense Advanced Research Projects Agency (DARPA) is a Defense Agency within the Department of Defense that has a unique role. It is not tied to a specific operational mission: DARPA supplies technological options for the entire Department, and is designed to be the "technological engine" for transforming DoD. It has been the originator of several technologies that have consequently shaped our world, such as computer networking and global positioning systems. Its success is often attributed to the freedom it has to pursue high-risk, cutting edge research.

[33] ARPA-E did not receive any appropriations in the 2008 omnibus bill and remains unfunded.

[34] Alic et al., 2003.

[35] Newell, September 2007.

[36] See Kosar, K.R., *The Quasi-Government: Hybrid Organizations with Both Government and Private Sector Legal Characteristics,* CRS Report for Congress RL30533, Congressional Research Service, 2007.

[37] Alic et al., 2003.

Fall 2008

Printed on recycled paper

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