U.S. Technology and Innovation Policies to Address Climate Change

Technological innovation on a global scale will be needed to mitigate global climate change. To significantly reduce emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs), three types of technological innovations are needed: (1) more efficient technologies that use less energy to deliver valuable services such as electricity and transportation; (2) technologies to expand the use of alternate energy sources with lower or zero GHG emissions, such as renewable energy (e.g., wind and solar); and (3) technologies to capture and sequester the CO_2 from fossil fuels before (or after) it enters the atmosphere, such as disposal in geologic formations. Technological change will be instrumental in reducing costs, widening applicability, and improving reliability in these three categories, and will be required to reduce emissions of the non-CO_2 GHGs as well.

The most effective way to bring about these innovations is through a combination of technology policy incentives that encourage climate-friendly technologies, and environmental policies such as a cap-and-trade program that limits GHG emissions. Lessons learned from the United States' rich experience with technology and innovation policies can be applied to GHG-reduction efforts, and include the following:

- **A balanced policy portfolio must support not only research and development (R&D), but also promote diffusion of knowledge and deployment of new technologies: R&D, by itself, is not enough.**
- **Support for education and training should supplement research funding.**
- **Policies that do not directly promote technological innovation (i.e., "non-technology policies") still provide critical signposts for prospective innovators by indicating technological directions likely to be favored by future markets.**
- **Policy-makers should channel funds for technology development and diffusion through multiple agencies and programs, because competition contributes to policy success.**
- **Public-private partnerships can foster helpful, ongoing collaborations.**
- **Effective programs require insulation from short-term political pressures.**
- **Regulatory and marketplace certainty help create favorable conditions for firms to invest in new climate-friendly technologies.**
- **Policy-makers must be prepared to tolerate some "failures" (i.e., investments that do not pay off), and learn from them as private sector entrepreneurs do.**
- **In light of the inherent uncertainty in innovation, government policies should generally support a suite of options rather than a specific technology or design.**

Government policies will be critical to the development and adoption of a portfolio of new technologies needed to abate global climate change. Widespread adoption of these new technologies—for electric power generation, transportation, industry, and consumer products—is required in any major effort to reduce the greenhouse gas (GHG) emissions that contribute to climate change. However, technological change on an economy-wide scale cannot happen overnight. Well-crafted government policies in both the short and long term will be instrumental in encouraging more rapid development, deployment, and diffusion of climate change mitigation technologies,[1] and will be essential complements to environmental policies that set limits on GHG emissions—such as a GHG cap-and-trade program. Implementing these policies in the near term is essential for creating an environment in which technological innovation can thrive and contribute to GHG reductions. The United States—a global leader in innovation—is well placed to lead such technological change and hence enjoy benefits in terms of global competitiveness in new energy and other GHG mitigation technologies.

Private firms tend to under-invest in technology development, making government policy for technological innovation necessary. This under-investment occurs because environmental externalities (such as climate change) are undervalued. In addition, firms that invest in technology innovation cannot retain all of the benefits of their expenditures because the knowledge that they gain "spills over" to competing firms. As a result, although most innovations come from private firms, government policies of many types influence the rate and direction of technological change.

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Global research and development (R&D) funding trends indicate that both governments and private firms are under-investing in energy technology R&D. In the United States, federal government energy technology R&D budgets declined 74 percent between 1980 and 1996 (from $5 billion to $1.3 billion), and were accompanied by declines in private sector investments.[2] Similar funding declines have occurred throughout the industrialized world.[3] Because the United States is a global leader in R&D, the nation's under-investment in energy technology R&D has particularly disturbing implications for global efforts to address climate change. The research, development, and diffusion of new technologies necessary to address climate change will require coordination between the public and private sectors, and across nations.

This brief summarizes the role of technological change in GHG mitigation strategies, provides a taxonomy of technology policies, and gleans lessons learned from U.S. technology and innovation policies. It concludes with policy insights for spurring technological innovation in the effort to address climate change.

The Role of Technological Change in GHG Control Strategies

Climate change is one of the most far-reaching and formidable environmental challenges facing the world. The earth is undoubtedly warming, largely as a result of GHG emissions from human activities including industrial processes, fossil fuel combustion, and changes in land use, such as deforestation. Continuation of historical emission trends will result in additional warming over the 21st century, with current

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projections of a global increase of 2.5°F (1.4°C) to 10.4°F (5.8°C) by 2100, and warming in the United States expected to be even higher. Potential consequences of this warming include sea-level rise and increases in the severity or frequency (or both) of extreme weather events, including heat waves, floods, and droughts. The risks of these and other consequences are sufficient to justify action to significantly reduce GHG emissions.

In the United States, energy consumption is the dominant source of GHG emissions. Carbon dioxide (CO_2) accounts for approximately 84 percent of total GHG emissions. Although other GHGs[4] have a more powerful effect on global warming per molecule, CO_2 enters the atmosphere in far greater quantities because it is produced whenever fossil fuels are burned.[5] To significantly reduce these emissions, three types of technological innovations are needed: (1) increased energy efficiency for technologies that deliver valuable services like electricity and transportation; (2) technologies to expand the use of alternate energy sources with lower or zero GHG emissions; and (3) technologies to capture and sequester CO_2 from fossil fuel combustion before (or after) it enters the atmosphere.

Technological change will be instrumental in reducing costs, widening applicability, and improving reliability in efforts to reduce emissions of CO_2 and non-CO_2 gases alike.

Stabilizing atmospheric concentrations of CO_2 and other GHGs at a "safe" level, the international goal under the United Nations Framework Convention on Climate Change,[6] would have profound implications for industrial and industrializing economies alike. Human activity now adds around 8 billion metric tons of GHGs to the earth's atmosphere each year, a total that is growing approximately 4 percent annually.[7] A widely discussed goal of stabilizing atmospheric CO_2 at twice the pre-industrial level by 2100 (i.e., at 550 parts per million, 65 percent higher than today's concentration) implies worldwide CO_2 reductions on the order of 60 to 80 percent below projected "business as usual" levels for the remainder of the 21st century. Substantial reductions in U.S. CO_2 emissions would require that the United States replace or retrofit *hundreds* of electric power plants and substantially improve the efficiency of *tens of millions* of vehicles. In addition, appliances, furnaces, building systems, and factory equipment numbering in the hundreds of millions might also need to be modified or replaced.

Technological change on this scale cannot happen immediately. Many of the technologies needed do not yet exist commercially or require further development to reduce costs or improve reliability. Technology policies, such as those outlined in the next section, can help spur technological change.

Table 1

A Summary of U.S. Technology Policy Tools

I. Direct Government Funding of R&D

Policy	Strengths	Weaknesses	Other Comments
1. R&D contracts with private firms.	Proven effectiveness in mission agencies, especially defense.	In the absence of a well-defined and widely accepted mission, can be hard to defend politically and to manage; may attract pork-barrel spending.	Established mechanisms, ample experience base for selection of technical objectives and evaluation of competing proposals.
2. R&D contracts and grants with universities.	Many centers of research excellence; strong competition (for funds, faculty, graduate students, etc.).	Applicable experience base is smaller for applied R&D than for more basic work.	Well-established agency procedures.
3. Intramural R&D conducted in government laboratories.	High levels of expertise and excellent facilities in some laboratories.	Generally poor track records in laboratories that lack strong, stable sense of mission and/or strong links with civilian users.	Few laboratories deeply integrated into national technological infrastructure (which may, for example, slow outward or inward technology flows).
4. R&D contracts with industry-led consortia or collaborations among two or more of the actors above.	Collaboration can help define technical objectives and minimize unnecessary duplication of effort.	Pre-competitive consortia tend toward lowest-common-denominator R&D. Firms that compete with one another may be reluctant to contribute their best people and ideas. Absorption of results by participants may be difficult.	Some duplication in R&D is often desirable. Recent vogue for "partnerships" may have discouraged objective evaluations of actual performance.

II. Direct or Indirect Support for Commercialization and Production; Indirect Support for Development

Policy	Strengths	Weaknesses	Other Comments
5. Patent protection.	Powerful incentive for innovation in some industries and technologies.	The stronger the protection, the weaker the incentives for diffusion through imitation or circumvention.	Most effective in pharmaceuticals, chemicals, and basic materials, where "inventing around" patents is difficult.
6. R&D tax credits.	Popular, relatively uncontroversial.	Difficult to target toward particular technologies.	Firms normally pursue R&D and commercialization for business reasons which tax credits affect little if at all; credits likely to subsidize work that would be conducted anyway.
7. Tax credits or production subsidies for firms bringing new technologies to market.	Well-suited, at least in principle, to targeting of particular technologies.	Subject to attack as corporate welfare and susceptible to political manipulation.	The larger the credits or subsidies, the more likely they will go to the best lobbyists rather than the best ideas.
8. Tax credits or rebates for purchasers of new technologies.	As above, but tend to pull technologies into the marketplace rather than pushing from the supply side.	As above, though less likely to attract lobbying because benefits are harder to channel to particular firms.	

Policy	Strengths	Weaknesses	Other Comments
9. Government procurement.	Powerful stimulus when government is a major customer.	In the absence of mission-imposed discipline, political considerations may dominate.	
10. Demonstration projects.	Can validate technologies, explore applications where market has yet to develop.	Tainted by past undertakings widely viewed as wasteful and ineffective, including energy projects in the 1970s and 1980s.	Technical objectives may be compromised by need to show positive results in order to maintain political support and funding.

III. Support of Learning and Diffusion of Knowledge and Technology

Policy	Strengths	Weaknesses	Other Comments
11. Education and training.	Powerful, pervasive mechanisms for diffusion of knowledge.	Many established channels act quite slowly (e.g., university degree programs). Workforce training policies fragmented and underdeveloped compared with education.	Quality, particularly in shorter education/training courses, can be highly variable. Formal education and training are best suited for transmission of information and knowledge that is already widely accepted as valid and broadly useful.
12. Codification and diffusion of technical knowledge.	Expert consensus on best practices reduces technical risks and uncertainties.	Design of programs that are well matched to varied institutional or sectoral environments is difficult and poorly understood.	Many well-established mechanisms (reference documents, consensus best practices, computer-aided engineering methods and databases, technical review articles, etc.) fall outside traditional government purview.
13. Technical standard-setting.	Potential for deep and lasting impacts.	Consensus standards development slow; often leads to compromise among competing private interests with limited public-interest input. May lock in inferior technologies.	Special interests have powerful incentives to seek to dominate the process.
14. Industrial or technology extension services.	Can directly address knowledge gaps, misunderstandings.	Labor-intensive; costly to reach large numbers of firms or individuals.	Long-term acceptance and viability yet to be fully established, except in agriculture.
15. Publicity, persuasion, and consumer information.	Possible to reach large numbers of people and organizations at relatively low cost.	Unlikely to alter vested interests or have much effect on cost-based decisions.	Competing interests may distort the message. Many Americans are skeptical and/or cynical about information from government.

Source: Alic, John A. "Policies for Innovation: Learning from the Past." In V. Norberg-Bohm, ed. The Role of Government in Technology Innovation: Insights for Government Policy in the Energy Sector (Belfer Center for Science and International Affairs, Harvard University, October 2002), Table 2, pp. 25-26.

A Taxonomy of Technology Policies

Technological change is a complex process with multiple stages and feedbacks. These stages include "invention" and "innovation," which are distinct activities. Invention refers to the process of discovery that leads to scientific or technological advance, perhaps in the form of a demonstration or prototype. Innovation refers to the translation of the invention into a commercial product or process. "Adoption," or "diffusion," occurs when these products and processes are actually used.

Although many types of policies affect invention and innovation, no universally accepted nomenclature or taxonomy summarizes or describes them. Economists often use the term "technology policy" to describe the diverse collection of measures that somehow affect technological development, and these are the focus of this brief. Taxonomies of technology policies seldom include regulatory policies, such as environmental regulations and antitrust enforcement, which have in the past catalyzed innovation and adoption and are discussed in a subsequent section of this brief.

Different policies influence outcomes at different stages of technology development. Table 1 on pages 4–5 lists fifteen common technology policy tools grouped into three broad categories, with comments on the strengths and weaknesses of each. The first category is direct government funding for R&D. The second category is a collection of policies that directly or indirectly support commercialization and adoption, or indirectly support development. The final group includes policies that foster technology diffusion through information and learning.

Lessons Learned from U.S. Technology and Innovation Policies

Although the United States has never had a coherent set of technology policies, government actions have profoundly influenced the rate and direction of technological change. Federal policies affecting technological change began with the codification of the patent system in the U.S. Constitution. Federal land grants supported the U.S. system of publicly financed colleges and universities, which became major players in R&D and innovation. In addition, government procurement during World War I transformed an infant aircraft industry that had produced only a few hundred planes; by the war's end, U.S. firms had manufactured some 14,000 planes, learning a great deal in the process. Government-spurred innovation accelerated in the post-World War II period. Despite the heterogeneity in federal policies—or perhaps because of it, given the high levels of uncertainty that characterize innovation—government actions have been remarkably effective. Lessons learned from this rich experience are supported by a large body of literature in economics and other fields concerning innovation, and include the following:

- **Technological change is a complex process involving invention, innovation, adoption, learning, and diffusion of technology into the marketplace.** The process is highly iterative, and different policies influence outcomes at different stages. For example, the U.S. government spurred diffusion of know-how in microelectronics through policies including antitrust and defense procurement. In response to a federal government antitrust suit, AT&T released technical information about the transistor (which it invented), licensed the relevant patents at nominal rates to all comers, and refrained from producing transistors for outside sale. Texas Instruments then introduced the first commercially successful transistor, and the Department of Defense (DoD) and its contractors began to design the new devices into radar, sonar, missile guidance, and communications systems, stimulating further learning and cost reductions. In addition, DoD procurement contracts stipulating that the chips be available from at least two suppliers led to the sharing of design and process know-how, which encouraged new market entrants and accelerated inter-firm technology flows.

- **Gains from new technologies are realized only with widespread adoption, a process that takes considerable time and resources and typically depends on a lengthy sequence of incremental improvements that enhance performance and reduce costs.** For example, several decades of significant government and private sector R&D investments occurred before gas turbines derived from military jet engines improved in efficiency and reliability to the point that they were cost-effective for electric power generation. Today, gas turbines are the leading technology for new, high-efficiency power plants with low GHG emissions.
- **Technological learning is the essential step that paces adoption and diffusion.** "Learning-by-doing" contributes to reductions in production costs, and adopters of new technology contribute to ongoing innovation through "learning-by-using." Widespread adoption, in turn, accelerates the incremental improvements from learning by users and producers, further fueling adoption and diffusion. For example, an entirely new class of products emerged as Intel (and soon, other firms) designed successive families of microprocessors, based in large part on feedback from users. When Intel began work on its 386 processor family, the lead technical and marketing specialist spent six months simply visiting customers to understand the features they valued most highly.
- **Technological innovation is a highly uncertain process.** Because pathways of development cannot be predicted, government policies should support a portfolio of options, rather than a particular technology or design. The unforeseen explosive diffusion of the Internet during the 1990s is illustrative. Both the Internet's technologies and many of the formal and informal governance mechanisms that evolved to coordinate its standards and infrastructure sprang from DoD-sponsored networking research and trials.

In addition to these insights gained regarding the innovation process, lessons learned from U.S. experience with technology policies over the past several decades include the following:

- **Federal investments contribute to innovation not only through R&D but also through "downstream" adoption and learning.** For example, in the early years of computing, defense agencies made indispensable contributions to a technological infrastructure that propelled the industry's rise to global dominance.

> ***Despite the heterogeneity in federal policies—or perhaps because of it, given the high levels of uncertainty that characterize innovation—government actions have been remarkably effective.***

- Public-private R&D partnerships have become politically popular because they leverage government funds and promote inter-firm collaboration. **Partnerships may have particular advantages in fostering vertical collaborations**, such as those between suppliers and consumers of energy.
- Adoption of innovations that originate outside a firm or industry often requires substantial internal investments in R&D and human resources. **Smaller firms may be less able to absorb innovations without government assistance.**
- Just as competition in markets helps resolve uncertainties and improves economic performance, **competition within government can improve performance in fostering innovation**. The messy and often duplicative structure of U.S. R&D support and related policies creates diversity and pluralism, fostering innovation by encouraging the exploration of many technological alternatives.
- Because processes of innovation and adoption are lengthy and convoluted, **effective policies and programs require sustained political support**. Reliable political constituencies have been essential for the development of new technologies in defense and for research in the biomedical sciences. By contrast, technology policies for addressing climate change face a discordant political environment.

Regulatory policies create an overall incentive and framework for innovation by mandating pollution reductions.

Regulatory Policies and Technological Innovation

In addition to the technology policies discussed above, environmental and other regulatory policies can strongly influence the process of technological change. Regulatory policies create an overall incentive and framework for innovation by mandating pollution reductions. Such policies have influenced the development and deployment of many technologies over the past 30-plus years. For example, environmental regulations drove innovations in automobile engines and electric power plants that have contributed to widespread improvements in air quality. Regulatory policies will likewise be required to stabilize atmospheric GHG concentrations because technology policies, while important, cannot by themselves achieve the GHG reductions necessary to mitigate climate change. Rather, technology policies should be part of a comprehensive approach that includes "non-technology policies," such as a GHG emissions cap-and-trade program.

Environmental policies respond to market failures that leave economic actors with little incentive to reduce activities that have adverse effects on society as a whole, such as releasing harmful substances into the atmosphere or water. The design of these regulations plays an important role in the extent and quality of innovation. Poorly designed environmental regulations can significantly inhibit innovation, and the overall timing and stringency of regulations can determine the extent to which innovation occurs or is used. Moreover, environmental policies must provide regulatory certainty—that is, they must reassure investors that additional future regulations will not impair the value of near-term investments made to comply with the original environmental policy. To foster the greatest innovation, environmental regulations should be designed to provide incentives to firms to both prevent and reduce pollution, such as by:

- **Reducing use of polluting technologies;**
- **Selecting cleaner processes when installing new technologies or capital equipment;**
- **Continually striving to improve the environmental performance of existing processes or technologies; and**
- **Placing control technologies on existing plants to reduce emissions.**

Regulations can be designed to assist innovation by promoting the greatest breadth of pollution reduction alternatives at the lowest possible cost. Many past environmental policies have relied heavily on "command-and-control" regulations that compel polluters to reduce their emissions to specified levels. Greenhouse gas emissions, however, are more suitably controlled through market-based approaches—such as emissions fees, pollution charges, or emissions cap-and-trade programs—because GHGs are emitted across all economic sectors around the world, and mix uniformly in the atmosphere. Thus it matters little precisely where the emission reductions take place, so long as they are real and verifiable. Traditional rate-based or technology-based standards, for example, would create little incentive for ongoing improvements in operational techniques to address climate change. The more recent turn toward "market-based" approaches for addressing climate change has created better incentives for continuous pollution reduction and technological innovation by giving firms greater flexibility and permitting compliance with regulations at lower cost.

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Patterns of capital investment by businesses also can have a major impact on the success and cost-effectiveness of climate change policies.[8] Capital stock, such as electricity generation plants, factories, and transportation infrastructure, is expensive and firms are often reluctant to retire old facilities and equipment. Certain policies can stimulate more rapid turnover of existing capital stock. These include putting in place early and consistent incentives that would assist in the retirement of old, inefficient capital stock; making certain that policies do not discourage capital retirement; and pursuing policies that shape long-term patterns of capital investment. In addition, even a modest carbon price could stimulate investment in new capital equipment. Likewise, uncertainty is likely to impede investment in new capital stock until the rules with respect to climate policy and other future environmental regulations are clarified.

U.S. energy and transportation policies also have influenced technology innovation and adoption. U.S. energy policy has often incorporated familiar tools of technology policy, such as tax credits for adoption of renewable energy technologies. Although the United States has long avoided energy pricing policies and fuel taxes to encourage energy efficiency, a substantial boost in gasoline taxes would likely be a powerful stimulus for innovation in automotive technologies.[9] Fuel economy for cars and trucks could be increased by 25 to 33 percent over the next 10 to 15 years using market-ready technology at a net savings, if fuel savings are taken into account. However, since fuel economy is undervalued in the marketplace, policies such as mandatory GHG standards and public information are needed to pull technological improvements into the market.[10] Because the goals of U.S. energy policy and the most effective methods to achieve them remain politically controversial, future choices—e.g., to encourage conservation or encourage fossil fuel production—could either support or undermine the goal of achieving GHG reductions.[11]

Because there can be no learning without some failures, policy-makers cannot expect every government investment to pay off.

Policy Guidance for Climate-Related Technology and Innovation Policies

Greenhouse gas emission reductions will require a broad portfolio of policies to foster technology innovation and adoption by stakeholders ranging from multinational corporations to households. The policy portfolio should combine technology policies as discussed in this brief with other policies to induce innovation and deployment.[12]

A climate change policy response must account for uncertainties in the pace and cost of innovation. Technological evolution is always accompanied by unknowns concerning the levels of performance that can ultimately be achieved, the technological attributes that will prove most attractive to adopters, and the costs of these technologies. Technical design and development are fluid, open-ended activities with multiple choices and trade-offs and often-ambiguous selection criteria. Uncertainties can be resolved only through learning processes. These processes are often slow and piecemeal, studded with lessons from both successes and failures. Technology-oriented policies and non-technology policies alike must function in such settings. Additional lessons for climate change policy include the following:

- **Because the benefits of technological innovation come only with widespread adoption, and because adoption and learning are mutually reinforcing processes, the policy portfolio should support diffusion of knowledge and deployment of new technologies as well as research and discovery. In short, R&D alone is not enough.**

A well-balanced portfolio of government policies that stimulates innovation, incentivizes adoption, and avoids picking winners is the best path forward to meet the challenges of global climate change.

- Because private investments respond primarily to near-term market incentives, public investments are necessary to build a technological infrastructure able to support innovation over the long term. A key ingredient of such infrastructure is a vibrant community of technologists and entrepreneurs working in settings in which knowledge and information flow freely. Government financial support for education and training, as well as for research, enhances such infrastructure. Intellectual property rights are important, but excessively strong intellectual property regulations may weaken such infrastructure.
- Competition among firms contributes to effective selection of innovations, and competition among academic research groups contributes to discovery. Similarly, competition among government agencies and government laboratories contributes to policy success. Competition exposes ineffectual bureaucracies, out-of-touch government laboratories, poor policy choices, and project-level mistakes. It encourages diversity by opening alternatives for exploration by technology creators and technology users alike. For these reasons, policy-makers should channel new funds for R&D through multiple agencies and allocate funds to industry and other researchers on a competitive basis.
- Because there can be no learning without some failures, policy-makers cannot expect every government investment to pay off. They must be prepared to tolerate mistakes, and to learn from them, just as entrepreneurs in the private sector do. In addition, policy-makers must be willing to accept a balanced portfolio that provides sufficient and sustained funding for both short- and long-term R&D. This means avoiding the temptation to pick "winners and losers" too early in the development phase of new technologies. Nonetheless, tolerance for error is no excuse for sloppy management or ill-conceived policies and programs.

Conclusions

Much technological innovation will be needed to mitigate global climate change. The most effective way to bring about these innovations is through a combination of technology policy incentives that accelerate the deployment of climate-friendly technologies and help create new markets for these products and processes, and environmental policies such as a GHG cap-and-trade program that sets limits on GHG emissions. Implementing these policies in the near term is imperative. A well-balanced portfolio of government policies that stimulates innovation, incentivizes adoption, and avoids picking winners is the best path forward to meet the challenges of global climate change.

For the complete text of this "In Brief" and other Pew Center reports or to order a free copy, visit our website at www.pewclimate.org.

[1] Alic, John A., David C. Mowery, and Edward S. Rubin. *U.S. Technology and Innovation Policies: Lessons for Climate Change*. Pew Center on Global Climate Change. Arlington, VA. November 2003. This brief draws heavily from this report.

[2] As calculated using constant U.S. 1996 dollars in Margolis, Robert M. and Daniel M. Kammen. "Evidence of under-investment in energy R&D in the United States and the impact of federal policy." *Energy Policy* 27: 575-584. 1999.

[3] *Ibid*.

[4] The principal GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and a range of industrial gases including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

[5] From an environmental and economic standpoint, effective climate strategies should address CO_2 as well as non-CO_2 GHGs, and control of non-CO_2 gases could be especially important and cost-effective in the near term. See Reilly, John M., Henry D. Jacoby, and Ronald G. Prinn. *Multi-gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of Non-CO_2 Gases*. Pew Center on Global Climate Change. Arlington, VA. February 2003.

[6] *United Nations Framework Convention on Climate Change* (1992), to which the United States is a signatory.

[7] Intergovernmental Panel on Climate Change. *Climate Change 2001: Synthesis Report*. Cambridge, UK: Cambridge University Press. 2001. This report includes a range of energy and emissions scenarios for the next century.

[8] For a more complete discussion of capital cycles and their implications for climate change policy, see Lempert, Robert J., Steven W. Popper, and Susan A. Resetar. *Capital Cycles and the Timing of Climate Change Policy*. Pew Center on Global Climate Change. Arlington, VA. October 2002.

[9] For more information, see Greene, David L. and Andreas Schafer. *Reducing Greenhouse Gas Emissions from U.S. Transportation*. Pew Center on Global Climate Change. Arlington, VA. May 2003.

[10] *Ibid*.

[11] For a more complete discussion of the role of energy policy in addressing climate change, see Smith, Douglas W., Robert R. Nordhaus, and Thomas C. Roberts, et al. *Designing a Climate-friendly Energy Policy: Options for the Near Term. Pew Center on Global Climate Change*. Arlington, VA. July 2002.

[12] See *The U.S. Domestic Response to Climate Change: Key Elements of a Prospective Program*. In Brief, Number 1. Pew Center on Global Climate Change. Arlington, VA.

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