U.S. Technology and Innovation Policies: Lessons for Climate Change*

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Foreword

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New technologies for electric power generation, transportation, industry, and consumer products are expected to play a major role in efforts to reduce the greenhouse gas (GHG) emissions that contribute to global climate change. Yet technological change on this scale cannot happen overnight. Government policies will be instrumental in encouraging more rapid development and adoption of technology. In the United States—long a leader in innovation—well-crafted policies that encourage the development, deployment, and diffusion of new technologies will be essential complements to other GHG-reduction policies.

The Pew Center commissioned this report to examine U.S. experience with technology and innovation policies—both successes and failures—and to draw lessons for future applications, including efforts to address climate change. The authors found that because innovation is a complex, iterative process, different policy tools can be employed as catalysts at various phases (e.g., invention, adoption, diffusion). They also discuss the roles that intellectual property protection and

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regulatory policies play in driving innovation, and examine programs such as the Defense Advanced Research Project Agency (an innovative force in information technology), as well as public-private collaborations such as the Partnership for a New Generation of Vehicles, to glean lessons for climate change policy. The insights revealed are clear:

- A balanced policy portfolio must support not only 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.
- "Non-technology policies" 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.
- 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 processes, government policies should generally support a suite of options rather than a specific technology or design.

Technology policies, while important, cannot by themselves achieve the GHG reductions necessary to mitigate climate change. Rather, they should be part of a comprehensive approach that includes "non-technology policies," such as a GHG cap-and-trade program. The authors and the Pew Center thank Bob Friedman, Ken Flamm, David Hart, and Ev Ehrlich for commenting on previous report drafts.

EXECUTIVE SUMMARY

Large-scale reductions in the greenhouse gases (GHGs) that contribute to global climate change can only be achieved through widespread development and adoption of new technologies. In the United States, energy consumption is the dominant source of GHG emissions. Most of these emissions consist of carbon dioxide (CO_2), which accounts for approximately 84 percent of total GHG emissions. Although other GHGs, such as methane (CH4), have a more powerful effect on global warming per unit of release, CO_2 enters the atmosphere in far greater quantities because it is produced whenever fossil fuels are burned. Thus the technological innovations needed to reduce GHG emissions and eventually stabilize GHG concentrations in the atmosphere are those that can, at reasonable cost: (1) improve the efficiency of energy conversion and utilization so as to reduce the demand for energy; (2) replace high-carbon fossil fuels such as coal and petroleum with lower-carbon or zero-carbon alternatives, such as natural gas, nuclear, and renewable energy (e.g., wind and solar); (3) capture and sequester the CO_2 from fossil fuels before (or after) it enters the atmosphere; and (4) reduce emissions of GHGs other than CO_2 that have significant impacts on global warming.

Although innovation cannot be planned or programmed, and most innovations come from private firms, government policies of many types influence the rate and direction of technological change. This report identifies technology policy tools that have fostered innovation in the past (see summary table below) and draws lessons for GHG abatement. It also briefly discusses other measures such as environmental regulations that would serve to induce innovation.

A Summary of Technology Policy Tools

Direct Government Funding of Research and Development (R&D)

- R&D contracts with private firms (fully-funded or cost-shared).
- R&D contracts and grants with universities.
- Intramural R&D conducted in government laboratories.
- R&D contracts with industry-led consortia or collaborations among two or more of the actors above.

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

- Patent protection.
- R&D tax credits.
- Tax credits or production subsidies for firms bringing new technologies to market.
- Tax credits or rebates for purchasers of new technologies.
- Government procurement.
- Demonstration projects.

Support for Learning and Diffusion of Knowledge and Technology

- Education and training (technicians, engineers, and scientists; business decision-makers; consumers).
- Codification and diffusion of technical knowledge (screening, interpretation, and validation of R&D results; support for databases).
- Technical standard-setting.*
- Technology and/or industrial extension services.
- Publicity, persuasion, and consumer information (including awards, media campaigns, etc.).

The key lessons of this analysis are supported by a large body of literature in economics and other fields concerning the innovation process, and include the following:

- ***Technological innovation is a complex process involving invention, development, adoption, learning, and diffusion of technology into the marketplace.*** The process is highly iterative, and different policies influence outcomes at different stages.
- ***Gains from new technologies are realized only with widespread adoption, a process that takes considerable time and typically depends on a lengthy sequence of incremental improvements that enhance performance and***

* Refers only to standards intended to ensure commonality (e.g., driving cycles for comparing automobile fuel economy), or compatibility (e.g., connectors for charging electric vehicle batteries), not to regulatory standards.

reduce costs. For example, several decades passed 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.*** Adopters of new technology contribute to ongoing innovation through "learning-by-using." Widespread adoption accelerates the incremental improvements from learning by both users and producers, further speeding adoption and diffusion.
- ***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.

Government policies influence technological change at all stages in 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.*** Government procurement of jet engines, for example, accelerated the development of gas turbines by providing a (military) market that allowed users and producers to gain experience and learn by using. Likewise, in the early years of computing, defense agencies made indispensable contributions to a technological infrastructure that propelled the industry's rise to global dominance.
- 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 insulation from short-term political pressures.*** Reliable political constituencies have been essential for the development of new technologies in defense, for research in the biomedical sciences, and for agricultural and manufacturing extension. By contrast, technology policies for addressing climate change face a discordant political environment.

Technology policies alone cannot adequately respond to global climate change. They must be complemented by regulatory and/or energy pricing policies that create incentives for innovation and adoption of improved or alternative technologies. Such "non-technology policies" induce technological change, with powerful and pervasive effects. Environmental regulations and energy efficiency standards have fostered innovations that altered the design of many U.S. power plants and all passenger cars over the past several decades. The technological response to climate change will depend critically on environmental and energy policies as well as technology policies. Because climate change is an issue with time horizons of decades to centuries, learning-by-doing and learning-by-using have special salience. Both technology policies and regulatory policies should leave "space" for continuing technological improvements based on future learning. Climate change policy must accommodate uncertainties, not only regarding the course and impacts of climate change itself, but also in the outcomes of innovation