

**TECHNOLOGY POLICIES
FOR REDUCING GREENHOUSE GAS EMISSIONS**

PROJECT SUMMARY

**A RESEARCH PROJECT OF
THE H. JOHN HEINZ III CENTER FOR SCIENCE, ECONOMICS AND THE ENVIRONMENT**

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Technology Policies for Reducing Greenhouse Gas Emissions

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Executive Summary

A well-crafted technology policy can help accelerate the development and adoption of new technologies for lowering emissions of greenhouse gases (GHGs). But the design task is not simple. GHG sources are widely dispersed globally and in terms of economic activity. Hundreds or thousands of technologies are involved. The goal of this project was to develop a taxonomy of technology policies that could help decisionmakers link policy levers with emissions sources. Such an approach might also encourage decisionmakers to look more closely at technology policies that have not been part of the current debate, which has centered on funding levels for existing R&D and deployment programs of the Department of Energy (DOE) and other agencies.

This report gives an overview of the taxonomy, discusses the institutional context, and summarizes reactions of a workshop convened to discuss the project. Both the taxonomy and workshop are the subjects of more extensive reports.¹ The project dealt only with technology policies, not with regulatory or other environmental policies. Principal findings include the following:

- The portfolio of U.S. technology policies for addressing GHG emissions could be better balanced in two ways. First, through added support for radical innovation. Second, through better structured policies for promoting diffusion and deployment of new technologies.
- In part because the nation's science and technology system is so highly decentralized, effective policy implementation depends on a widely shared sense of mission to discipline agency-level decisions. At present, no compelling GHG reduction mission exists. Consensus on such a mission would not only improve the government's management of GHG-related technology programs, it would help guide policy selection.
- Almost any portfolio of technology policies aimed at GHG reduction would gain added force from complementary price signals and regulatory initiatives. "Pulling" innovations into the marketplace through incentives often leads to better solutions than does "technology push."
- Government, in cooperation with industry, universities, and environmental groups, should expand the effort to construct technology "roadmaps" and balanced *technology policy* roadmaps for addressing GHG release. This would not only serve budgetary and planning purposes but help build a sense of mission.

The potential impacts of GHGs are unknown but could be far-reaching. Regardless of whether they turn out to be major or minor, these impacts will operate over lengthy time scales, a

¹ "Technology Policies for Controlling Greenhouse Gas Emissions: A Taxonomy" and "Meeting Summary: Workshop on Technology Policies for Controlling Greenhouse Gas Emissions," available at www.heinzctr.org or by request from the Heinz Center.

half-century and longer. This is a consequence of the “inertia” associated both with climatic processes and the economic activities that contribute to GHG accumulation. All countries and almost all industry sectors are implicated in GHG release and all countries will experience the consequences, whatever those might be. Innovation on the scale needed to substantially reduce GHG emissions could, over the longer term and given well-designed policies that encourage entrepreneurial innovation, usher in a new wave of technologies with revolutionary implications for economic growth and wealth creation.

* * *

This report, and the taxonomy of policies, seeks to inform decisionmakers regardless of their views. Even global warming skeptics, for example, might wish to support a modest but diversified policy portfolio as insurance against outcomes they deem unlikely. At present, the U.S. policy portfolio is narrow, with most of the emphasis on R&D programs managed by DOE. In one sense this is no surprise, given that GHGs stem primarily from energy consumption and that DOE accounts for the bulk of federal energy R&D.² But it does not necessarily follow that this is the best policy, given what is known about the sources of innovations and their diffusion in technologically dynamic economies.

The scale and scope of worldwide GHG emissions imply that radical innovation will be needed for substantial reductions even in the rate of increase of GHG release. Innovations, moreover, whether incremental or radical, have little impact until widely diffused. “Breakthroughs” sometimes originate in research, but not always: the microprocessor began as a pure exercise in engineering design (Box A). Despite such examples, relatively little attention has gone toward non-R&D technology policies.³

In theory, market pull generated by rational economic calculation paces diffusion and deployment of new technologies. Businesses invest when expected returns exceed those of alternative expenditures. Consumers maximize their welfare when they buy furnaces or refrigerators, weighing purchase price against operating costs. In actuality, few consumers appear to act this way.⁴ Box B suggests that firms may be little more “rational.” Strong economic incentives

² In the United States, transportation, buildings, and industrial production contribute in roughly equal proportions to GHG emissions that make up about one-fifth of the world total. Most GHGs stem from energy consumption, including electric power, which goes primarily to the buildings and industry sectors. For details, see Emissions of Greenhouse Gases in the United States 1997, DOE/EIA-0573(97) (Washington, DC: Department of Energy, Energy Information Administration, October 1998). The Energy Department’s “five-laboratory study,” “Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond,” prepared by the Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies for Office of Energy Efficiency and Renewable Energy, Department of Energy, Washington, DC, September 22, 1997, focused primarily on R&D. In a similar vein, “Federal Energy Research and Development for the Challenges of the Twenty-First Century,” Report of the Energy Research and Development Panel, President’s Committee of Advisors on Science and Technology [PCAST], Washington, DC, November 5, 1997, called for increasing DOE’s applied energy R&D budget by about \$1 billion over half a dozen years.

³ But see, for discussion of longer-term, higher-risk energy technologies, John P. Holdren, “Federal Energy Research and Development for the Challenges of the 21st Century,” Investing in Innovation: Creating a Research and Innovation Policy That Works, Lewis M. Branscomb and James H. Keller, eds. (Cambridge, MA: MIT Press, 1998), pp. 312-315.

⁴ “Studies have found that residential consumers demand a short payback period for efficiency investments - 2 years or less for home appliances, for example. Many decisionmakers are driven by the desire to keep first-costs low; few pursue the goal of minimizing life-cycle costs” Energy Efficiency: Challenges and Opportunities for Electric Utilities (Washington, DC: Office of Technology Assessment, September 1993), p. 78.

do not currently exist to pull new GHG-reducing technologies into the economy. Even if they did, they might not suffice to drive innovation and deployment unless these incentives

Box A - Innovation without Research

The origins of the microprocessor had little to do with research. Intel's 1971 invention resulted from a customer request for a set of specially-designed integrated circuits for a four-function calculator; instead, Intel's engineers created a programmable chip that could emulate a calculator.⁵ They had no notion where their design would lead. The idea was new, but it was simply a shortcut, a way of emulating other chips - not yet the idea of a "computer on a chip." Even in this age of organized R&D, radical innovation sometimes begins in serendipity.

Box B - Diffusion Among Businesses

Case studies of technologies including numerically-controlled (NC) machine tools suggest that business investments do not necessarily follow from implicitly or explicitly calculated financial returns. Diffusion of NC equipment in U.S. industry proceeded quite slowly, rising from perhaps 1000 machines in 1960 to 14,000 in 1968, about 0.5 percent of the machine tool base. The numbers reached 40,000 in 1978, and 94,000 by 1983 - still only 5.5 percent of installed machine tools.⁶ Surveys indicate that many firms simply failed to understand the implications of NC for their costs.⁷

Just-in-time (JIT) production and related workplace innovations such as quality circles do not, in general, require capital investments. They do require learning. Diffusion from Japan proceeded slowly. It took American industry around 15 years to adopt methods that spread more quickly elsewhere. Institutional factors explain the difference. Within Japan, industry and employer associations helped codify "best practices" and transmit them among firms. Large manufacturers helped their suppliers; government programs aided unaffiliated small manufacturers. In the United States, business, trade, and professional groups played less of a role.⁸ And just as many firms were slow to see what NC could do for them, they were slow to grasp the logic of workplace reorganization.

turned out to be comparable, say, to those that transformed the microprocessor from a niche product into a breakthrough.

⁵ Federico Faggin, "The Birth of the Microprocessor," *Byte*, March 1992, pp. 145-150.

⁶ The development and diffusion of NC equipment has been extensively studied. For a short summary, see John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston, MA: Harvard Business School Press, 1992), pp. 350-354.

⁷ See, for instance, *Current Industrial Reports: Manufacturing Technology 1988* (Washington DC: U.S. Department of Commerce, Bureau of the Census, May 1989.)

⁸ Robert E. Cole, *Strategies for Learning: Small-Group Activities in American, Japanese, and Swedish Industry* (Berkeley: University of California Press, 1989).

The nation's GHG-related policy portfolio would benefit from measures to foster radical innovation that go beyond research, such as government procurement, and from policies to speed diffusion and deployment, including carefully crafted technology demonstrations. Policies should seek to create demand conditions under which innovation will flourish. To the extent that GHG release is viewed as a potentially grave problem, the objective should be to replicate conditions like those that gave rise to the waves of innovation sweeping through electronics and computing over the past half-century (Box C). Of course, there are many and profound differences between the two cases. The point is that these differences include more than technology and economics: they extend to the policy setting.

The striking characteristic of current GHG-related technology policies is the emphasis on R&D under the DOE umbrella and following paths first marked out during the energy "crises" of the 1970s. In contrast, the striking characteristics of the information technology revolution include the many federal agencies involved, the wide range of policies with significant impacts (e.g., deregulation of telecommunications, which helped stimulate growth of the Internet), and the influence of users (many of whom went on to build businesses based on their own experiences). The information technology case is special. But so is the GHG case. Careful policy design with involvement by multiple agencies and attention particularly to demand creation –

Box C - *Fostering Innovation in Information Technologies*

A recent report from the National Research Council, Funding a Revolution, stresses the often unexpected contributions of government in creating a dynamic technological environment:⁹

*Federal research has been most effective when it concentrated on work that industry has limited incentive to pursue: **long-term**, fundamental research; **large system-building efforts** that require the talents of **diverse communities** of scientists and engineers; and work that might **displace existing, entrenched technologies**.*

*... federal mechanisms ... need to ... build in sufficient **flexibility to accommodate mid-course changes** and respond to unanticipated results.*

*Projects that appear to have failed often make significant contributions to later technology development or **achieve other objectives***

*Research ... is a highly **unpredictable** endeavor. [The] most important contributions often differ from those originally envisioned.*

e.g., through procurement - could help generate a dynamic setting for innovation and creative risk-taking like that in information technology.

⁹ These quotations come from the prepublication version of Funding a Revolution: Government Support for Computing Research, Computer Science and Telecommunications Board, National Research Council, November 1998. Emphasis added.

A Taxonomy of Technology Policies

Because this project dealt only with technology policies, the taxonomy (Table 1) is restricted to measures that are voluntary for industry or consumers while requiring government funding or other action. The table divides 14 policy categories into three groups. Those in the first group involve R&D spending. Policies in the second group induce private R&D (and/or engineering design and development, D&D), support commercialization and production, or do both. The third group includes measures that foster diffusion and deployment through information transmittal and learning.

Some of the policy tools in the taxonomy are suited to direct promotion of specific technologies - amorphous photovoltaic cells, say - through “technology push” or “market pull.” Because commercialization - bringing new technologies to market - is almost entirely a private-sector activity, the push-pull distinction can be viewed in terms of business decisions. Firms must make judgments concerning two kinds of risk or uncertainty, technical and business. Technical risk refers to the possibility that target values for critical performance parameters, including costs, may not be achieved. Business risks stem primarily from uncertainties concerning revenues. If a new product fails to sell in the quantities expected, the firm may not recoup its expenditures even if the product is a resounding technological success.

As indicated in Table 2, R&D funding reduces technical risk by generating knowledge that can verify feasibility and narrow uncertainties concerning performance. Such policies tend to push technology into the marketplace from the supply side. Other policies function by increasing the incentives for commercialization, thereby pulling technology from the demand side. Rebates for purchasers can have this effect, raising demand and reducing business risks. So can low-interest loans or loan insurance. Diffusional policies, too, can reduce uncertainty, informing businesses or the public of best practices and thereby reducing the risks of adopting new technology.

As the tables indicate, technology policy does not begin and end with R&D. The reflexive turn to research when faced with a technology issue tends to mirror political opposition to measures that some see as verging on “industrial policy,” whereas support for R&D, especially basic research, is viewed, almost regardless of political philosophy, as safe and appropriate (a perspective evident in the workshop). At the same time, policymakers have often made exceptions in cases sanctioned by precedent, as in agricultural extension (discussed in a later section).

Table 1
Technology Policies ^a

Direct Funding of R&D/D&D

1. R&D contracts with private firms (fully-funded or cost-shared)
2. R&D contracts and grants with universities
3. Intramural R&D conducted in government laboratories
4. R&D contracts with consortia that include two or more of the actors above

Indirect Support for R&D/D&D; Direct or Indirect Support for Commercialization and Production

5. R&D tax credits
6. Tax credits or production subsidies for firms bringing new technologies to market
7. Tax credits or rebates for purchasers of new technologies (e.g., negative gas guzzler taxes on new motor vehicles)
8. Government procurement (e.g., energy-efficient buildings)
9. Demonstration projects

Information and Learning

10. Education and training (technicians, engineers, and scientists; business decisionmakers; consumers)
11. Codification and diffusion of technical knowledge (e.g., screening, interpretation, and validation of R&D results, support for databases)
12. Technical standards-setting (e.g., for recharging electric vehicle batteries) ^b
13. Technology and/or industrial extension services
14. Publicity, persuasion, consumer information (including awards, media campaigns, etc.)

^a The taxonomy omits policies such as intellectual property protection that create generalized incentives for innovation.

^b This entry refers only to technical standards intended to ensure commonality (e.g., driving cycles for testing automobile fuel economy and/or emissions) or compatibility (e.g., connectors for charging electric vehicle batteries), not to regulatory standards.

Table 2

Technology Policies for GHG Reduction by Function/Impact

<i>Policy Category</i>	<i>Reduction in Technical Risk (Technology Push)</i>		<i>Reduction in Business Risk (Market Pull)</i>	
	<i>Knowledge Creation (R&D)</i>	<i>Knowledge Application (Development & Commercialization)</i>	<i>Through Financing</i>	<i>Through Information</i>
1. R&D contracts with private firms	√	√	Minor	
2. R&D contracts and grants with universities	√			
3. Intramural R&D conducted in government laboratories	√			
4. R&D contracts with consortia that include two or more of the actors above	√	Possible if private firms participate.	Minor	
5. R&D tax credits	Modest impacts possible.			
6. Tax credits or production subsidies for firms bringing new technologies to market		√	√	
7. Tax credits or rebates for purchasers of new technologies			√	
8. Government procurement		√	√	
9. Demonstration projects	√	√	√	√
10. Education and training		√		√
11. Codification and diffusion of technical knowledge		√		√
12. Technical standards-setting		√		√
13. Technology/industrial extension		√		√
14. Publicity, persuasion, consumer information				√

Note: The absence of a check mark in this table does not imply the absence of impact, simply that impacts will usually be less than for checked entries.

Workshop Conclusions

While industry participants at The Heinz Center workshop believed that new and more cost-effective technologies may be key to lowering GHG emissions, they expressed cautions concerning technology policy, especially the need to view each industry and each technology on its own terms. The workshop was notably positive about the contributions of federally funded research, particularly grants to universities. Other promising policy tools, when used appropriately, include: R&D contracts to industry consortia; government procurement; education and training of engineers, scientists, and technicians; publicity (as illustrated by the Baldrige award for quality practices); and consumer information.

In contrast, R&D tax credits were viewed as unlikely to influence corporate research objectives, though some participants thought they might increase overall levels of R&D spending. Other tools viewed as inappropriate or ineffective for lowering GHG emissions included R&D contracts with individual firms and old-style, large-scale demonstration programs such as those associated with the Synfuels Corporation and the breeder reactor. On the other hand, several participants pointed out that these were not necessarily representative, arguing that well-conceived demonstrations would boost prospects for some GHG-related technologies.

Modest expectations for technology policies stemmed in part from two often inter related factors. Past successes seem to correlate with 1) the perceived depth of political support for a clear, common mission and 2) the consistency and duration of policies. Energy technology policies have not enjoyed the same depth of support as, for example, those for defense or biomedical research. Similarly, initiatives to spur the development of energy technologies have typically had lifetimes of a few years as opposed to decades of consistent attention to military technologies and health care.

As already mentioned, workshop participants emphasized the central role for government in knowledge creation, especially through university research, while noting that attention should be paid to other approaches, too. Government procurement has sometimes been a major force in inducing creation of new knowledge as well as fostering product development and early commercialization. Participants did warn, however, that federal acquisition regulations can discourage firms that do not regularly pursue government contracts.

Participants were skeptical about the benefits of such finance mechanisms as tax credits for producers or purchasers of new technologies - again, at least over the too-short time they typically remain in place. Incentives make sense, they believed, only if the technology appears sufficiently attractive to eventually succeed in the marketplace on its own, in which case appropriate policy measures can accelerate the process.

The participants felt strongly that a diverse portfolio of approaches would be needed to have significant impact. They emphasized that each industry differs, not only in technologies, but in factors such as the significance of intellectual property protection and the willingness of firms to work together. The participants suggested that if government were truly serious about matching a portfolio of technology policies to specific sectors and technology challenges, it

should undertake joint planning with industry to produce *policy* roadmaps similar to the technology roadmaps pioneered by the semiconductor industry (discussed in a later section) and adopted by others including DOE's Industries of the Future program. Such exercises can help all parties understand future needs and plan effectively. Subsequent technology development efforts might be conducted jointly (as illustrated by the Partnership for a New Generation of Vehicles, PNGV), by industry consortia without government participation (e.g., the Electric Power Research Institute, which has its own roadmap initiative underway), or through government-supported research in universities. Roadmaps not only foster knowledge creation but can address commercialization and eventual diffusion on a sector-by-sector basis.

Technology Policy Strengths and Weaknesses

Some of the 14 policies in the taxonomy are costly, others nearly free. The United States has much experience with some (R&D contracts and grants), little with others (industrial extension). Some agencies have good track records with particular tools, poor records - or simply little experience - with others. The listing below includes brief comments on each of the categories:

1. *R&D contracts with private firms.* Standard tool, familiar and effective in mission agencies, especially defense.
2. *R&D contracts and grants with universities.* Well established procedures in many agencies.
3. *Intramural R&D conducted in government laboratories.* Even laboratories with excellent facilities and highly qualified staffs are not as well integrated into the technological infrastructure as universities.
4. *R&D contracts with consortia that include two or more of the actors above.* Collaboration reduces unnecessary duplication and builds in diffusion, but precompetitive consortia may tend toward lowest-common-denominator agendas.
5. *R&D tax credits.* Noncontroversial but unlikely to affect corporate objectives.
6. *Tax credits or production subsidies for firms bringing new technologies to market.* Can in principle create strong impetus for targeted technologies. Opponents may label such policies, with which the United States has little experience, as "corporate welfare."
7. *Tax credits or rebates for purchasers of new technologies.* Tend to "pull" technologies into the marketplace, which can be more desirable than "pushing" them.
8. *Government procurement.* Powerful stimulus where government is a significant customer. Regulations and paperwork discourage some potential bidders.
9. *Demonstration projects.* Can directly address technical risk, but tainted by past undertakings viewed as wasteful and ineffective.
10. *Education and training.* Powerful and well-accepted mechanism for diffusion. Training underdeveloped compared to higher education.
11. *Codification and diffusion of technical knowledge.* With exceptions such as public works, not a traditional role for government in the United States.
12. *Technology/industrial extension.* Relatively new except in agriculture, with little institutional experience.

13. *Technical standards-setting.* Compromise among competing private interests may lock in inferior technologies.
14. *Publicity, persuasion, consumer information.* Can reach large audience at low cost, though conflicting interests may attenuate message.

The full taxonomy report, cited in footnote 1, includes a more comprehensive treatment of the advantages and disadvantages of each policy tool.

Agency Mission

More than a dozen federal agencies implement technology policies. Each has a different institutional approach and experience base. The Department of Defense (DoD), which accounts for about half of all government R&D spending - roughly \$35 billion of \$70-plus billion - supports a very wide range of technologies. DoD, for instance, laid much of the groundwork for the information technology revolution, through procurement as well as R&D (Box D).

Box D - Lessons from Defense

For decades, defense has been a spawning ground for innovation. During the early years of the semiconductor industry - i.e., through the 1960s - DoD procurement had greater impacts than R&D.¹⁰ Integrated circuits, at the time too costly for commercial application, went into military systems (and the Apollo project). Nascent merchant semiconductor firms captured the lion's share of sales and accounted for the major technical advances. Government procurement nurtured an industry that soon left its military roots behind.

R&D funding did have significant influence. Perhaps most important, university research grants supported large numbers of students in leading graduate schools. Freshly minted Ph.D.'s joined the new firms springing up in Silicon Valley and elsewhere, carrying the latest knowledge with them and spurring successive rounds of innovation.

While military influence on the semiconductor industry waned as commercial sales increased, DoD procurement continues to support developments in gas turbine engines. The high-efficiency turbine-driven electric generators that have become common in the civilian power industry descend from jet engines designed for military aircraft. (Until the 1990s, all the engines for large commercial aircraft were designed around military "cores.") The same technical advances that lead to greater thrust-to-weight ratios in aircraft yield higher operating efficiencies in stationary applications. Year by year since the 1950s, incremental innovation driven by DoD purchases has contributed to increases in performance.

DOE, which traces its ancestry to the Atomic Energy Commission (AEC), also has a national security mission. Responsible for nuclear weapons, DOE's energy R&D originates in AEC support for civilian nuclear power. Even now, energy technology is a relatively small part

¹⁰ See *Beyond Spinoff*, pp. 257-265, and the sources cited therein.

of DOE R&D - about \$1.3 billion of a 1997 total of \$6 billion - though accounting for about 90 percent of the federal energy technology total.¹¹ About one-third of the energy R&D budget is spent inside DOE's own laboratories. Some of these laboratories are dominated by a weapons culture; all suffer from an awkward and long-contested division of management responsibilities between Washington and the field.¹² Since World War II, DoD has cultivated ties with universities and private industry as part of its search for innovations in military systems. Thus most of the advances in gas turbine technology noted in Box D came, not from the military's own laboratories, but from outside; university research groups made many contributions to the analytical techniques used in gas turbine design and to the high-temperature materials on which performance depends. Engine manufacturers conducted similar work, often more applied, along with product/process engineering. By contrast, DOE, with end-to-end responsibilities for tightly classified nuclear weapons technologies, has been more insulated from external influences.

Other agencies exhibit their own patterns. The National Institutes of Health (NIH) funds research in the biomedical sciences, some in its own laboratories but most on an extramural basis. The NIH mission in support of research is so deeply ingrained that hardly any attention goes to diffusion even though it is nearly impossible for physicians to keep up with advances in knowledge, many studies have shown that average standards of medical practice lag far behind consensus best practices, and the federal government pays more than 25 to 30 percent of a health care bill that now consumes 14 percent of national income.

While the NIH mission has come to be defined almost entirely in terms of research, the U.S. Department of Agriculture (USDA) has, since early in the century, budgeted substantial sums for diffusion in the form of extension work with farmers.¹³ Agricultural extension had its genesis as part of the larger effort to improve rural living conditions around the turn of the century, a time of widespread poverty among farm families. An entrenched lobby and widespread nostalgia for a vanishing way of life keep these programs in place.

USDA has been unique in the United States in its emphasis on diffusion (Box E). Although both DOE and the Environmental Protection Agency have implemented diffusion-

¹¹ "Federal Energy Research and Development for the Challenges of the Twenty-First Century" provides a detailed analysis of energy R&D spending on pp. 2-3 - 2-15.

¹² Ever since the transfer of the weapons laboratories to the AEC from the Army, which had run the Manhattan Project during World War II, efforts to maintain a balance between mission-oriented work on nuclear warheads and the more academic research environment needed to attract and retain highly qualified scientists and engineers have contributed to an uneasy compromise between centralized authority and local autonomy. See Robert W. Seidel, "A Home for Big Science: The Atomic Energy Commission's Laboratory System," Historical Studies in the Physical Sciences, Vol. 16, 1986, pp. 135-175. In recent years, the DOE laboratories have come in for considerable criticism - e.g., "Alternative Futures for the Department of Energy National Laboratories," Secretary of Energy Advisory Board, Task Force on Alternative Futures for the Department of Energy National Laboratories, February 1995 [the Galvin report].

¹³ USDA's ratio of spending on R&D to diffusion, around 2:1, contrasts with ratios of 90:1 or 95:1 in other agencies. Everett M. Rogers, J.D. Eveland, and Alden S. Bean, "Extending the Agricultural Extension Model," report of the Institute for Communication Research, Stanford University, September 1976.

oriented energy conservation programs that fall within the third grouping in the taxonomy, few appear to have been evaluated for effectiveness.¹⁴

Box E - *Diffusion-Related Policies*

Most observers would place the United States at or near the mission-oriented pole on a technology policy spectrum from mission-oriented to diffusion-oriented. Small, wealthy countries like Sweden tend to emphasize diffusion (thus workplace practices such as the quality circles mentioned in Box B spread more rapidly in Sweden than here). Germany and Japan occupy intermediate positions. They resemble the United States in putting a good deal of emphasis on government R&D, while doing more to foster diffusion - e.g., through workforce training.

The underdeveloped state of institutions for diffusion in the United States is a legacy of the 1950s, the seminal decade for technology policy. In the aftermath of World War II, with American industries well ahead of those elsewhere, policymakers were content to let diffusion, deployment, and spinoff take their own course. Government would support basic research - in part because wartime experience had shown this to be vital for defense - along with mission-oriented technology development. Other policies were off the table unless protected, as at USDA, by powerful constituencies. Only at the end of the 1980s did the Department of Commerce begin putting in place technology extension programs, modeled after those in Japan and elsewhere, to help smaller manufacturing firms (in part because of evidence that such firms were underinvesting in innovations such as the NC machine tools discussed in Box B).

Among the agencies, DoD has been almost alone in contributing to long-term, high-risk technology development other than through research. The National Science Foundation (NSF), like NIH, seeks to generate new knowledge. USDA diffuses practices, not products: suppliers of seeds, chemicals, and agricultural equipment commercialize USDA-supported research, just as drug companies base new products on NIH research. Although the National Aeronautics and Space Administration (NASA) purchases goods and services from technology-intensive firms in pursuit of its mission, it does so in small volumes compared to DoD. NASA, moreover, tends to be technically conservative because of the high costs of failure, especially where human life might be endangered.

Defense agencies, alone, spend large sums on exploratory development and testing of quite speculative systems - e.g., ballistic missile defense - simply to see if they will work. Sometimes, the Pentagon pursues objectives viewed as critical with multiple, competing programs. As a number of workshop participants noted, DoD's approach, though expensive and failure-prone, has been accepted because national security provides a compelling mission supported across the political spectrum.

¹⁴ More than 40 programs for reducing GHG emissions, many of them intended to encourage deployment, are listed in [Climate Action Report: 1997 Submission of the United States of America Under the United Nations Framework Convention on Climate Change](#), Department of State Publication 10496 (Washington, DC: Department of State, July 1997).

Consistent public and political support are in fact part of what it means to have a “mission.” NASA’s mission originated in the space race with the Soviet Union; when formed in 1958, the agency took over the Army’s ballistic missile programs and a number of Air Force and Navy rocket and satellite projects. DOE is responsible for nuclear weapons because Congress, in the aftermath of World War II, believed that atomic bombs should be in civilian hands. Energy technology has not had remotely comparable status.

Coordination and Management: Technology Policy Roadmaps

Internalized control mechanisms are vital in government, if only because the incentives and reward structures found in private industry are lacking. As several workshop participants observed, a widely-shared sense of mission helps discipline both day-to-day activities and major decisions. Members of Congress may seek to steer military work to their districts, but few would do so at genuine risk to the nation’s security. Pentagon officials learned the value of scientific and technical expertise during World War II and ever since have listened seriously to advisory boards and panels. Disputes between “disease lobbies” and NIH turn on questions of research priorities, not pork-barrel funding. Peer review at NSF has sometimes been criticized, but no one contends that cronyism runs rampant over merit.

Internal control mechanisms are doubly important in science and technology. The nation’s S&T system is decentralized if not fragmented. There is no unified S&T budget. Neither the White House nor Congress can routinely tell agencies what to do with their R&D dollars and expect them to do it. Priorities set at high levels shape but cannot determine the multitude of individually small decisions made at working levels. Many of these decisions, after all, involve esoteric matters that few but initiates can fully understand. Effective policies and programs depend on an agreed and compelling mission, one that is embedded in the institution rather than imposed from above.

The many “critical technologies” exercises undertaken since the latter part of the 1980s represent part of the effort to improve federal R&D management.¹⁵ By the mid-1990s, industry-wide technology roadmaps, often prepared through trade associations, had also become common (Box F). As pointed out at the workshop, these plans, with their timelines, can help managers in industry as well as government decide how to allocate resources (e.g., where public funds might be needed to compensate for market failures, where companies can rely on the common knowledge base).

Roadmaps have so far been used almost exclusively for R&D planning. In the case of GHG release, they could also be turned to the design of non-R&D technology policies. Maps that lay out technical needs by industry sector could be brought together to construct national, intersectoral roadmaps. Moreover, because the global scope of GHG release suggests that

¹⁵ In December 1998, RAND’s Science and Technology Policy Institute, formerly the Critical Technologies Institute, released the most recent of these, [New Forces at Work: Industry Views Critical Technologies](http://www.rand.org/publications/MR/MR1008/MR1008.pdf), <www.rand.org/publications/MR/MR1008/MR1008.pdf>

international cooperation in technology development will be an eventual part of any full-scale assault, roadmaps could become vehicles for planning joint international programs.

Box F - *New Modes of R&D: Roadmaps and Collaboration*

Technology roadmaps seek to identify generic or “precompetitive” needs and opportunities, those that can benefit all firms in an industry. Maps prepared by the Semiconductor Industry Association in response to surging competition from Japan have been the best-known model.¹⁶

Roadmaps are part of a broader shift towards more collaborative forms of R&D, commonly falling under policy category 4 in the taxonomy. Government often provides some of the funding for a consortium involving several firms, and perhaps universities. Workshop participants expressed favorable views of Sematech, the most prominent example, in part because the consortium now operates without government money. (Until recently, DoD channeled \$100 million annually to Sematech, which was originally established under cover of national security needs.) PNGV, which links several agencies with automakers and industry suppliers, also got positive comments from the workshop.

Such forms of collaboration fall in a gray area between the two widely accepted roles for government: basic research and mission-related technology development. While advocates have urged new “missions” in support of competitiveness or energy conservation (both, in the case of PNGV), opponents have argued against what they see as industrial policy in the guise of technology policy. Recent and heated battles have been fought over the Commerce Department’s Advanced Technology Program, which survived, and the five-agency Technology Reinvestment Program, which did not. The underlying conflict over the appropriate role of government in the economy is deepseated and can be traced back generations.

Portfolio Considerations

The Executive Summary suggested that efforts to replicate the technological dynamism of digital electronics could help foster innovation and diffusion of GHG-related technologies. This would not be easy, of course, even if there were agreement on the dangers of global warming - which there is not. Yet even global warming skeptics - those who believe the scientific evidence to be shaky, that the consequences of whatever warming may occur will be small (or alternatively that it is likely to be easy to adjust to warming or compensate for GHG buildup) - might incline toward a modest portfolio of technology policies as a hedge against an uncertain future.

Innovation is unpredictable by definition. We know that technological and economic change will come. We do not know what forms they will take. Who, after all, predicted the explosive growth of the Internet in the early 1990s? Who can foresee the future of electronic

¹⁶ For an example of a map prepared in conjunction with DOE’s Industries of the Future Program, see “Metalcasting Industry Technology Roadmap,” Cast Metal Coalition of the American Foundrymen’s Society, North American Die Casting Association, and Steel Founders’ Society of America, January 1998.

commerce? Radical uncertainty implies that, while any portfolio of technology policies can be viewed as a bet or an insurance policy, there is no good way to handicap the bet or put an actuarially-based price on the policy. Among other things, a radically uncertain future implies that policies to stimulate pathbreaking innovations, even if only modestly successful in reducing GHGs, could contribute in unexpected ways to new technological opportunities, spurring economic growth and entrepreneurial wealth creation.

Those who accept the more dire global warming scenarios will be inclined to a broad and deep policy portfolio, particularly if they worry that the dynamics of climate change may prove incommensurate with those of markets (i.e., that it might be too late to reverse course once incontrovertible evidence of negative impacts appeared). They would prefer a head start in dealing with worst-case scenarios because the technological challenges seem unprecedented in their global scope, time horizon of decades to a century or more, numbers of technologies involved, and correspondingly widespread economic effects. Long-term, high-risk projects would be a priority, but so would policies for speeding diffusion of existing and near-term technologies. Policy tools would be chosen across most or all of the taxonomy. Advocates of such an approach would probably also favor diversification across agencies.

Such steps would appear to require a sense of mission lacking even during the energy crises of the 1970s. Today, the groups favoring GHG abatement cannot muster influence remotely comparable to the disease lobbies that argue for more money for NIH, the “military-industrial complex” that lines up behind NASA’s programs as well as DoD’s, or the farmers and agribusinesses that support USDA. Construction of a compelling mission, one that can discipline policy choice and agency management, is perhaps the biggest challenge for those who believe GHG release and global warming to be critical problems for the future.