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THE PCAST ENERGY STUDIES: Toward a National Consensus on Energy Research, Development, Demonstration, and Deployment Policy

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■ **Abstract** During the period 1995–1999, the President's Committee of Advisors on Science and Technology (PCAST) produced three major energy studies, at President Clinton's request. The panels that conducted these studies were broadly constituted from the academic, industrial, and NGO (nongovernmental organization) sectors, and their recommendations were unanimous. These efforts (*a*) helped lay the foundation for several major energy initiatives of the second Clinton term, including the Climate Change Technology Initiative, the Nuclear Energy Research Initiative, and the International Clean Energy Initiative; (*b*) helped launch energy R&D activities on methane hydrates and geological sequestration of carbon dioxide; and (*c*) strengthened related activities, such as the Partnership for a New Generation of Vehicles, the Partnership for Advancing Technologies in Housing, the fossil power Vision-21 Program, and the National Bioenergy Initiative. Federal budgets for research, development, demonstration, and deployment of advanced energy technologies have increased substantially over the past four years, but they still fall short of PCAST's recommendations; and a number of the PCAST recommendations on matters other than budget have yet to be fully implemented. The PCAST energy studies demonstrate the possibility of forging consensus around key energy issues and provide a foundation on which, it is hoped, the continuing pursuit of a coherent national policy on energy innovation will be able to build.

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*The work discussed here was done while Dr. Baldwin was on detail from the National Renewable Energy Laboratory to the National Science and Technology Council and prior to service at the Department of Energy (DOE). This article does not necessarily reflect the position of the DOE.

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INTRODUCTION

In response to successive requests from President Clinton, the President's Committee of Advisors on Science and Technology (PCAST) conducted three major energy studies during the period 1995–1999. The resulting reports (1–3) were "The U.S. Program of Fusion Energy Research and Development," July 1995 (1); "Federal Energy Research and Development for the Challenges of the Twenty-First Century," November 1997 (2); and "Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation," June 1999 (3). They are denoted here as PCAST-95, PCAST-97, and PCAST-99, respectively.

These three PCAST studies, each broader and more ambitious than the last, were not a package foreseen from the outset; they emerged individually, each shaped by the circumstances of its time. In the first Clinton-Gore term (1993–1996), the administration's energy activities included launching a number of important initiatives—notably the Partnership for a New Generation of Vehicles in September 1993 (4) and the Climate Change Action Plan in October of the same year (5)—as well as work to lay the foundations for later initiatives for advanced technology in housing and for bioenergy.[1] A review of the overall energy R&D strategy of

[1]Particular credit for these efforts goes to White House energy experts Henry Kelly, Assistant Director for Technology in the Office of Science and Technology Policy (OSTP); John H. Gibbons, Director of OSTP and the President's Science and Technology Advisor; and Vice

the Department of Energy (DOE) was being undertaken in 1994–1995 by the Secretary of Energy Advisory Board (SEAB), and consequently, initiating a broad energy R&D review by PCAST at that time would have seemed duplicative. The request that PCAST received, shortly after its formation in 1994, to study the US fusion R&D program was motivated not by any perception that fusion was an especially important part of the government's energy R&D portfolio, but rather by congressional insistence that the administration should review fusion research with an eye to how its budget could be reduced.

The PCAST fusion panel took the opportunity, however, to preface its review of the fusion program with a summary of the case for investments in the development of advanced energy technologies overall. Its argument on this was reinforced by the appearance, in the same year, of the superb report of the SEAB Task Force on Strategic Energy R&D (6) and, subsequently, by a December 1996 letter report from PCAST to the President on the science-and-technology-policy issues deserving more attention in the second term than they had received in the first (7). In listing energy R&D policy first among five such issues, that letter report had the following to say:

> Adequate and reliable supplies of affordable energy, obtained in environmentally sustainable ways, are essential to economic prosperity, environmental quality, and political stability around the world; and energy-supply and energy-efficiency technologies represent a multi-hundred-billion dollar per year global market. There is considerable doubt whether the world, which gets three quarters of all its energy supply from oil, coal, and natural gas, can continue to rely on these fossil fuels to this degree through the expected economic growth of the next few decades without encountering intolerably disruptive climatic change caused by the resulting greenhouse gas emissions. Yet the United States—which is the world's largest energy consumer, the largest greenhouse gas emitter, is 85-percent dependent on fossil fuels, and imports nearly half of its oil at a cost of $50 billion per year—has allowed Federal spending on energy R&D to fall more than 3-fold in real terms in the past 15 years, a period in which private funding for energy R&D also was falling. Government spending on energy R&D is more than twice as high in Japan as in the United States in absolute terms, and about four times as high as a fraction of GNP.

Five weeks later, in mid-January 1997, President Clinton responded with a formal request to PCAST to undertake a comprehensive review of the nation's energy R&D strategy.

The resulting PCAST study was completed in the fall of 1997, in time to provide input to the administration's budget request for FY 1999 as well as to the climate-change policy being formulated in preparation for the Kyoto Conference

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President Gore, who had a strong and long-standing interest in the intersection of climate policy and energy strategy.

of the Parties to the UN Framework Convention on Climate Change. The President's request, in the summer of 1998, for a further PCAST study of the possibilities for strengthening the federal government's support for international cooperation on energy-technology innovation was attributable in part to the 1997 report's recommendation that this be explored, and in part to the recognition, in the White House, that the best inducement for developing-country commitments to reducing greenhouse gas emissions below "business as usual"—commitments the Byrd-Hagel amendment (Senate Resolution 105-98) indicated would be required for the Kyoto Protocol to be ratified by the US Senate—was improved access to advanced energy technologies. It was also recognized, irrespective of Kyoto, that strengthened energy-technology cooperation would improve the access of US firms to foreign energy-technology markets and would help developing countries address a growing array of local and regional environmental problems.

In addition to reflecting the strong and growing conviction in the administration, through the latter part of the 1990s, about the importance of energy-technology innovation, the evolving and expanding mandates of the sequence of PCAST energy studies reflected a growing sophistication in the energy R&D community about the intricacies and challenges of the innovation process. Among the understandings that had been coming into focus in these years and the period leading up to them were the leverage to be found in pursuit of technologies that address multiple national goals (e.g., oil-import reduction, air-quality improvement, greenhouse gas abatement) simultaneously; the critical role, in the innovation process, of the linkages and feedback loops connecting the stages from fundamental research to applied research to development to demonstration and deployment; the particular importance of the mechanisms that are in place (or missing), beyond R&D as usually conceived, for demonstrating advanced energy technologies and driving down their costs to competitive levels; the appropriate roles of the public and the private sector in innovation processes—and the value of public-private partnerships; the need to develop a broad-based portfolio of energy RD^3 balanced across technologies, sectors, time frames, and risks; and the necessity of addressing many of these issues in a global context.

The panels formed by PCAST to conduct these studies included not only experts in the relevant energy topics but also a sprinkling of individuals of experience and stature in research or management outside the indicated energy field, who would not be expected to hold any a priori brief for the relevant federal R&D program. Members were drawn from the private sector, academia, and public-interest groups and included individuals with prior experience managing government programs of the sort under review. The diversity and balance of the panels magnified the challenge of reaching consensus on R&D needs and priorities, which historically has been contentious terrain on which competing constituencies have often tried to prevail by disparaging the prospects of all options but their favorites. But the challenge was also an opportunity, insofar as any agreement that such a group was able to reach would have more credibility with the wider community and with policy makers than would the recommendations of a narrowly constituted collection of known advocates for a particular position.

The findings of any study of this type emerge from an interaction of process, context, and content (where process includes the choice of participants, the mechanisms by which they interact, argue, and produce a report, and the means by which they solicit and take into account opinion and analysis from outside the group; context includes the relevant technical, environmental, economic, and political circumstances and issues of the day, the stances of relevant institutions and constituencies, and the results of recent studies of the same issue by others; and content refers to the kinds of data, analysis, and argument that are brought to bear and how these ingredients are combined and presented). And aspects of process and context, no less than the findings and underlying content of a report, influence its impact on decision makers and the wider, interested community (8, 9). In this article, therefore, we not only review the findings, recommendations, and underlying argumentation of the three PCAST energy studies and the fate of the recommendations in the administration and the Congress, but we also touch on the aspects of context and process that seem to us to have been most important in shaping the studies and the responses to them. We take up the three studies in the order in which they were produced.

PCAST-95—THE US PROGRAM OF FUSION ENERGY R&D

The first of the three PCAST energy studies—reviewing the US program of fusion energy research and development—was requested in late fall 1994, begun in early 1995, and completed in July 1995. Its origin was language in the FY 1995 Energy and Water Appropriations Act, specifying that the President should ask PCAST to review the fusion program and its budget. The core of the charge to the panel read (1, p. 60):

> The task of the panel is to clarify the technical and policy tradeoffs and budgetary requirements associated with—and recommended preferred alternatives among—various possible trajectories for the magnetic fusion energy program, including: (a) the trajectory currently programmed, (b) an alternative in which expenditures would increase in a similar manner but would be programmed differently, (c) an alternative in which expenditures would remain approximately constant, (d) an alternative in which expenditures would decrease moderately, and (e) an alternative in which expenditures would decrease sharply.

Further text in the charge made clear that the review was to focus only on the magnetic-fusion program and a small effort attached to it on possible applications of inertial-confinement fusion as an energy source. It excluded the larger inertial-confinement fusion program that has been funded under the Defense Programs division of the DOE because of the applications of this technology to the study of nuclear-weapon physics.

Context

The DOE budget for magnetic-fusion R&D at the time of the study (FY 1995) was $365 million (including $9 million for energy applications of inertial-confinement fusion), representing about a fifth of DOE spending on all applied-energy-technology R&D (fusion, fission, fossil, renewables, and end-use efficiency). This budget had been approximately constant in real (inflation corrected) terms throughout the 1990s, having fallen from a level about twice as high, in real terms, in the latter part of the 1970s. About 50% of the FY 1995 budget was allocated to moderate- to large-scale tokamak devices in the United States, including the design phase of a new national tokamak experiment designated TPX (for Tokamak Physics Experiment).[2] Another 18% ($71 million) represented the US contribution to the engineering design phase of ITER (the International Thermonuclear Engineering Reactor), a far larger and more powerful tokamak than any before it, being pursued as a joint venture of the United States, Russia, Japan, and the European Union.

Research on magnetic-fusion energy had been characterized by a growing degree of international cooperation since being declassified by the United States, the United Kingdom, and Russia in 1958, and ITER—expected ultimately to cost $10–14 billion for construction and operation—was slated to become the largest international energy R&D project in history. Prior to the collapse of the Soviet Union, its magnetic-fusion research program was larger than that of the United States, and in the mid-1990s Japan and Europe together were spending three times as much on magnetic fusion as the United States was.

The US National Energy Strategy, promulgated under President Bush in 1992, called for a substantial strengthening of the US fusion effort, aiming at operation of a demonstration reactor by about the year 2025 and commercial power plants by about 2040. To accommodate the US share of the cost of building ITER while supporting a domestic magnetic-fusion R&D program compatible with commercialization by 2040, the DOE's program plan called for budgets averaging almost $650 million per year in the decade FYs 1996–2005. But it was clear that in the climate of fiscal stringency of the mid-1990s, this sort of budget growth for fusion was not going to materialize. The assignment of the PCAST panel, plainly enough, was to find a way to restructure the US effort in magnetic-fusion R&D at a lower budget level than the FY 1995 figure, while protecting the most valuable elements of the program.

The US magnetic-fusion program was already arguably the most intensively reviewed energy R&D program in history. Just in the five years preceding the President's request for the PCAST study, these reviews included five reports (10–14), all of which explicitly or implicitly endorsed the goal of operating a demonstration

[2]The tokamak is a toroidal magnetic-confinement concept, originally developed in the Soviet Union in the 1960s, which became the dominant configuration in magnetic-fusion-energy research programs all around the world after demonstrating greater progress toward achievement of energy-breakeven conditions than competing approaches.

fusion reactor by about 2025, and nearly all of which called explicitly for the significant growth in R&D budgets needed to achieve this.

But the recommended increases had not materialized, and the US fusion community was increasingly divided along fracture lines of the sort that inadequate budgets tend to generate and aggravate: theoreticians versus experimentalists; physicists versus engineers and materials scientists; universities versus national laboratories; tokamak supporters versus advocates of alternative concepts; supporters of a strong US presence in ITER versus worriers that the growing cost of ITER would lead to crippling the domestic fusion-research base; researchers at the Princeton Plasma Physics Laboratory—which, with the largest US tokamak in operation (the Tokamak Fusion Test Reactor) and the only major new US machine on the horizon (TPX), controlled the lion's share of the US budget—versus everybody else. At the same time, the fusion budget was under fire from advocates of other energy options, who argued that fusion's share of the energy R&D pie was out of proportion to fusion's prospects in relation to those of, for example, solar energy, or advanced fission reactors, or energy end-use efficiency improvements. It was in this contentious environment that PCAST received the unenviable assignment of recommending how big the fusion budget should be and how it should be divided (and doing so without the mandate, time, or resources to undertake any comparative analysis of the benefits, on the margin, of another dollar spent on fusion R&D versus the benefits of spending that dollar in some other sector of energy R&D).

Process

The panel formed by PCAST to carry out this task was chosen with great care. It consisted of four members of PCAST itself and five other panelists picked for their particular relevant expertise. It included a strong advocate and a strong critic of ITER, physicists, engineers, theoreticians, experimentalists, individuals who had worked on fusion in universities, and others who had done so in national laboratories. It included three members from the private sector. Four of the nine members had no background in fusion and two no background in energy (although all had extensive backgrounds in R&D). A number had experience in fission or in nonnuclear energy technologies rather than—or in addition to—fusion. The only member from Princeton was not from the fusion community.

The panel met six times between late March and mid-June 1995. It read all, and was briefed on most, of the recent studies of the US fusion program conducted by others. It also received briefings from the DOE managers of the US fusion program; from representatives of all of the national laboratories and many of the universities engaged in fusion research; from leaders of the ITER project and of the fusion programs of Russia, Japan, and the European Union; from the fusion industry association; from a leader of the inertial-confinement fusion program; and from the associate director of the Office of Management and Budget. (All the briefings and associated discussions were held in closed session, to promote the candid expression of individual views.) In addition to the briefings, the panel received and digested some two dozen solicited and unsolicited letters and position papers from individuals in universities, national laboratories, and corporations.

The report was written by the full panel, with subdivided lead responsibilities for individual chapters. After extensive negotiation and revision, the text was agreed to unanimously, without expression of dissenting views on any point. It was subsequently endorsed by the full PCAST, and briefings on the report were organized for the secretary and deputy secretary of energy, the heads of the DOE's Office of Energy Research and Office of Fusion Energy, and officials of the Office of Management and Budget. Copies were provided to the President and the Vice President without briefings.

Content

The PCAST-95 report began with an account of the challenges of providing adequate supplies of energy in the twenty-first century in economically affordable, environmentally tolerable, and politically acceptable ways, noting that world electricity use in particular is likely to triple by the year 2050 and that none of the ways to meet this large increase in demand was free of constraints and/or uncertainties. It offered an argument for pursuing fusion energy not as a panacea but as a potentially important element of a portfolio approach to meeting energy needs at midcentury and beyond, noting (1, p. 9):

> Most of the major energy options, fossil and nonfossil alike, are subject to sharply rising costs of some kind—economic, environmental, social, political—when their scale of utilization passes a critical level. For example, hydropower, windpower, and solar energy become much costlier when it becomes necessary to resort to inferior sites; oil becomes much more dangerous politically when total demand grows so large as to require excessive dependence on the resources of unstable regions; fossil fuels altogether become much costlier environmentally when the scale of their emissions overwhelms the absorptive capacity of biogeophysical systems; nuclear fission will be problematic if it grows and spreads more rapidly than the managerial competence needed to operate it safely and protect its fissile materials; and so on . . . . In these circumstances, it should be obvious that there is great merit in the pursuit of diversity in energy options for the next century. There are not so many possibilities altogether. The greater the number of these that can be brought to the point of commercialization, the greater the chance that overall energy needs can be met without encountering excessive costs from or unmanageable burdens upon any one source. The potential value of developing fusion energy must be understood in this context. The potential costs of needing fusion at midcentury and beyond, but not having it, are very high.

The report then summarized the potential characteristics of fusion as an energy source, described the features of fusion R&D that would warrant support as fundamental science even in the absence of a prospective energy application, sketched out the scientific and funding history of fusion research and international collaboration with respect to it, and offered an analysis of the strengths and weaknesses of the then-current US program of R&D on magnetic fusion energy and the international efforts, most notably ITER, to which it is linked. The panel concluded from all this that the substantially increased budgets (compared with the FY 1995 level) being advocated by the Office of Fusion Energy in the DOE were reasonable. It wrote (1, p. 46):

> Based on the importance of developing energy sources adequate to meet the needs of the next century and the promise of fusion for this purpose, the benefits of fusion R&D in strengthening the national science and technology base, the impressive recent rates of progress in fusion research, the costs of the logical next steps, and the growing investments in fusion R&D being made in Europe and Japan (which already total more than three times the corresponding investment here), we believe there is a strong case for the funding levels currently proposed by DOE—increasing from $366 million in FY1996 to about $860 million in FY2002 and averaging $645 million between FY1995 and FY2005 (all in as-spent dollars). Spending less would drastically reduce the chance of meeting the National Energy Strategy goal of operating a fusion demonstration reactor by about 2025.

The panel then conceded that these budgets were, nonetheless, not going to materialize and turned to its primary task of recommending how "the most indispensable elements of the US fusion effort and associated international collaboration" could be preserved at a more realistic funding level.

The strategy it fashioned for this entailed stabilizing funding for magnetic-fusion R&D at about $320 million per year over a 10-year period, roughly $50 million less than the FY 1995 level and half of the average projected for FYs 1996–2005 under the then-prevailing plans of the DOE's Office of Fusion Energy. The principal priorities within this "budget-constrained" program were to be (*a*) a strong domestic core program in plasma science and fusion technology, exploring both advanced tokamak research and research on concepts alternative to the tokamak; (*b*) a collaboratively funded international fusion experiment with less ambitious performance goals than ITER and costing about three times less; and (*c*) an international program to develop the advanced, neutron-resistant materials needed to make fusion reactors that are economic and environmentally attractive.[3] Pursuing this strategy would entail a difficult negotiation with the United States' partners in ITER; if they did not agree to downsize the project, the United States would need to become a less-than-equal partner and perhaps would withdraw

[3]Fusion reactions generate large fluxes of energetic neutrons, which tend to degrade the integrity of ordinary materials that might be used in fusion-reactor structures. They also tend to convert some of the elements in those materials to radioactive forms ("neutron activation"), creating a radioactive-waste burden and hazards to workers, as well as a possible risk to the public through dispersion of these materials in severe accidents. Advanced materials have the potential to minimize these problems.

altogether, and there would be little prospect of international participation in a US TPX device or in a recommended international facility for testing advanced materials.

The panel made very clear that its recommendations represented a "second best" approach necessitated by budget realities. It wrote (1, p. 46):

> Embracing this strategy would entail hard choices and considerable pain, including straining the patience of this country's collaborators in the international component of the fusion effort, forcing difficult trade-offs between even a reduced US contribution to international collaboration and maintaining adequate strength in the domestic components of US fusion R&D, shrinking the opportunities for involvement of US industry in fusion-technology development, and surrendering any realistic possibility of operating a demonstration fusion reactor by 2025. But we believe it is the best that can be done within budgets likely to be sustainable in the current climate, and the least that can responsibly be done to maintain a modicum of momentum toward the goal of practical fusion energy.

Impact

The Secretary and Undersecretary of Energy indicated they found the recommendations sensible but said it was impossible for them to include in the DOE's budget proposal the amount recommended by PCAST for magnetic fusion, which represented a $50 million increase over the FY 1995 level: There was a ceiling on the energy part of the DOE's budget; there was no basis, in the panel's analysis, for taking the money out of another sector of energy R&D[4]; it was not permissible to transfer funds from the DOE's nonenergy functions (such as environmental remediation or nuclear weapons); and the DOE had agreed to refrain from asking for increases in its overall budget as part of a strategy, in a period of government budget austerity, to placate its critics in Congress.

Relief from these strictures could come only from a decision made above the level of the DOE, but efforts by the panel to secure such a decision were unsuccessful. The administration's FY 1996 request for a fusion budget, about the same as that for FY 1995, was rejected by Congress, despite appeals to Congressional energy leaders by members of the panel and by the fusion R&D community. The FY 1996 appropriation was about $240 million and that in FY 1997 about $230 million.

In the fusion community there was considerable praise for the report's argumentation and balance, but there was also some indignation, among US and international ITER advocates, that the panel had suggested reopening the question of the scale and scope of ITER (15). Little more than a year later, a DOE panel asked

[4]Such an analysis and recommendation would have been beyond the limited scope of the panel's mandate, which was confined to fusion. There was, of course, a sense of catch-22 in being asked to review fusion alone and then being told the findings were moot because a comparative analysis was missing.

to address how to cope with the large budget cuts imposed on the fusion program by Congress recommended that it be restructured as essentially a "science" program (from the mixed "science" and "energy" program it had been) and that the United States not commit to the construction phase of ITER (16). Not long thereafter, the ITER leadership announced a major redirection of effort toward developing a smaller, cheaper, less ambitious design (17).

It must be conceded, then, that the impact of PCAST-95 on the evolution of fusion R&D was limited. It failed to persuade the administration to fight for budgets big enough to keep the "energy" in the fusion energy program, and it failed to persuade the ITER community to undertake, in a more timely way, the downsizing that would ultimately be needed to save the project. The most that can be said is that it prepared the groundwork for the hard choices others recommended later about what to preserve in a shrinking US program and in a scaled-down ITER effort. Perhaps its larger accomplishment was that by framing the basic arguments about the energy challenges of the twenty-first century and the need for technological innovation to address them, and then failing to move the administration with its plea for action on fusion alone, it primed the pump for PCAST to promote a more comprehensive review of energy R&D strategy in the next round.

PCAST-97—FEDERAL ENERGY R&D FOR THE CHALLENGES OF THE TWENTY-FIRST CENTURY

The second PCAST energy study was requested by President Clinton at the beginning of his second term, in response to the December 1996 "priorities" letter from PCAST quoted in the introduction to this article (7). In a mid-January 1997 letter to PCAST Co-chair John Young (18), the President wrote: "In response to your recommendations, I have asked Jack Gibbons to work with the new Secretary of Energy . . . to review the current national energy R&D portfolio and make recommendations to me by October 1, 1997, on how to ensure that the United States has a program that addresses its energy and environmental needs for the next century."

Presidential Science and Technology Advisor Gibbons subsequently elaborated what was expected from the PCAST effort in support of this request in the following terms (19):

- a synopsis of the energy challenges likely to face the United States and the world in the early part of the 21st century with particular attention to the possible ramifications of these challenges for the country's economic well-being, environmental quality, and national security;
- a description of current and projected US energy R&D programs in relation to the identified challenges and in comparison to the R&D programs of other countries; and
- a detailed review of US government R&D programs in renewables, end-use efficiency, fission, advanced fossil-fuel, and fusion technologies—identifying priority and resource changes that would make the country's Federal energy

> R&D programs more responsive to the energy-linked economic, environmental, and national security challenges of the next century.

This charge was notable both in requesting that the study address the full range of energy options and in asking for detailed recommendations about what, in the existing federal energy R&D portfolio, should be changed. In the latter respect, the task given to PCAST went well beyond what had been undertaken in the review of federal energy R&D conducted by the SEAB two years earlier (5).

Context

In FY 1997, when the study was undertaken, federal budget authority for applied energy-technology R&D—that is, R&D focused specifically on developing or improving technologies for harnessing fossil fuels, nuclear fission, nuclear fusion, renewable-energy sources, and increased efficiency of energy end use—totaled about $1.3 billion.[5] Correcting for inflation, this was precisely what the country had been spending for applied energy-technology R&D 30 years earlier, in FY 1967, when real GNP was 2.5 times smaller and the reasons for concern about the adequacy of the nation's energy options were far less manifest (2, pp. 2–8).

As shown in Figure 1, federal applied energy-technology R&D spending ramped up sharply after the Arab-OPEC oil embargo of 1973–1974, reaching a peak of over $6 billion per year in FY 1978 in the process of adding sizable investments in advanced fossil-fuel technologies, renewables, and end-use efficiency to the fission- and fusion-dominated portfolio of the 1960s. After Ronald Reagan assumed the presidency in 1981, however, with his view that any energy R&D worth doing would be done by the private sector, applied energy-technology R&D spending fell threefold in the space of six years.[6] A Clean Coal Technology Program that was a joint venture of government and industry brought a brief and modest resurgence from 1988 to 1994, but thereafter the overall decline continued.

Similar declines in government-funded energy R&D were being experienced in most other industrial nations: The relevant expenditures fell sharply between 1985 and 1995 in all of the other G-7 countries except Japan (20). Japan's governmental energy R&D budget in 1995 was nearly $5 billion, in an economy only half the size of that of the United States. (Nearly $4 billion of the Japanese total was

[5]The "energy R&D" line in the DOE's budget contains a number of other categories that bring the FY 1997 total to almost $2.9 billion. These include Basic Energy Sciences (which includes research in materials science, chemistry, applied mathematics, biosciences, geosciences, and engineering that is not directed at developing any particular class of energy sources), biomedical and environmental research, radioisotope power sources for spacecraft, and some energy management and conservation programs that are not actually R&D at all. The PCAST-97 focus was primarily on the applied energy-technology R&D component, although one recommendation did address, in a general way, the "Basic Energy Sciences" part of the budget.

[6]Fusion suffered by far the smallest cuts of all of the energy options in this period, interestingly because Reagan's advisors persuaded him it was a "science" program rather than an "energy" program.

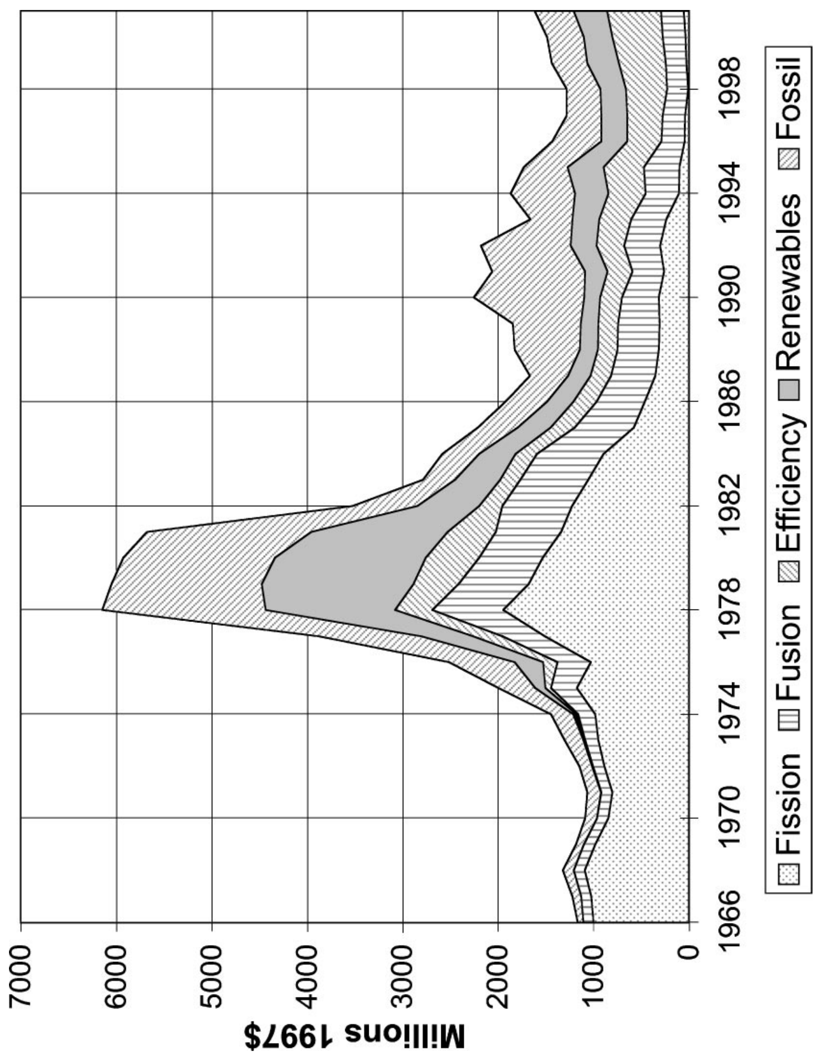

Figure 1 Federal energy-technology R&D spending, 1966-2001.

concentrated in nuclear fission and fusion, however, a pattern similar to that in the United States in the early 1970s.)

Private-sector energy R&D in the United States had been estimated by the 1995 SEAB study at about $2.5 billion per year at that time (5). Complete and consistent R&D figures for the private sector are difficult to assemble, but it appears these expenditures, like those of the federal government, had been shrinking for some time: The DOE estimated that US industry investments in energy R&D in 1993 were $3.9 billion (1997 dollars), down 33% in real terms from the 1983 level (21); a study at Battelle Pacific Northwest Laboratory showed US private-sector energy R&D falling from $4.4 billion (1997 dollars) in 1985 to $2.6 billion in 1994, a drop of about 40% (22).

Combined public and private investments in applied energy-technology R&D in the mid-1990s, at under $5 billion per year, amounted to less than 1% of the nation's expenditures on fuels and electricity. This meant that the energy business was one of the least research-intensive enterprises in the country, measured as the percentage of sales expended on R&D. Average industrial R&D expenditures for the whole US economy in 1994 were about 3.5% of sales; for software the figure was about 14%, for pharmaceuticals about 12%, and for semiconductors about 8% (23).

Why had energy R&D investments in the United States fallen so low? On the private-sector side, R&D incentives had been reduced by the rapid fall, since 1981, of the real prices of oil and natural gas (together constituting over 60% of the US energy supply) and by energy-sector restructuring (resulting in increased pressure on the short-term "bottom line," to the detriment of R&D investments with long time horizons and uncertain returns). Perennial factors limiting energy-industry R&D include the low profit margins that often characterize energy markets, the great difficulty and long timescales associated with developing new energy options and driving down their costs to the point of competitiveness, and the circumstance that much of the incentive for developing new energy technologies lies in externality and public-goods issues (e.g., air pollution, overdependence on oil imports) not immediately reflected in the balance sheets of energy sellers and buyers.

As for the government side of low propensity to invest in energy R&D, the "let the market do it" philosophy of the Reagan years was certainly important in the steep declines from FY 1981 through FY 1987. It was augmented by the bad taste left in the mouths of taxpayers and policy makers by the ill-fated government forays of the late 1970s into very-large-scale energy development and commercialization ventures (notably the Synfuels Corporation and the Clinch River breeder reactor); by the overall federal budget stringency characterizing the first Clinton term; by the targeting of the DOE by members of Congress as, allegedly, a particularly egregious example of a bloated and ineffective government bureaucracy; and by lack of voter interest—in the absence of gasoline lines, soaring energy bills, or rolling blackouts—in energy policy.

There was, finally, the "eat your siblings" character of energy-supply constituencies: the tendency of advocates of each class of energy options (e.g., nuclear fission, fossil fuels, renewables, energy end-use efficiency) to disparage the prospects of the other options—a tendency aggravated by the zero- or declining-sum-game characteristics of energy R&D funding in this period (4). In the grip of this syndrome, segments of the energy community itself formulated the arguments ("renewables are too costly," "fossil fuels are too dirty," "nuclear fission is too unforgiving," "fusion will never work," "efficiency means belt-tightening and sacrifice or is too much work for consumers") that the budget cutters cheerfully employed to cut energy R&D programs one at a time. There was no coherent energy-community chorus calling for a responsible portfolio approach to energy R&D that seeks to address and ameliorate the shortcomings of all the options.

While investments in energy R&D had been falling, however, concerns about the future adequacy of the country's portfolio of energy options had been growing. Imports as a fraction of US oil consumption, which had fallen from a high of 49% in 1977 to just 29% in 1985, had risen again to 51% by 1996 (24, pp. 7–9). The rate of decline of energy intensity of the US economy, which had averaged 2.8% per year from 1973 to 1986, had averaged only 0.9% per year between 1986 and 1996 (24, p. 16). The 1995 Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) had concluded that "the balance of evidence suggests a discernible human influence on global climate" (25) and that "climate change is likely to have wide-ranging and mostly adverse impacts on human health" as well as "negative impacts on energy, industry, and transportation infrastructure; human settlements; the property insurance industry; tourism; and cultural systems and values" (26). The United States, one of 170 nations to sign and ratify the United Nations Framework Convention on Climate Change in the early 1990s, had pledged along with other industrial-nation signers to hold its year-2000 greenhouse gas emissions to 1990 levels; but by 1996 US emissions of carbon dioxide, the most important anthropogenic greenhouse gas, were 9% above 1990 levels and rising (27). These were among the factors motivating PCAST's December 1996 call for greater administration attention to energy matters (7), which led in turn to the President's request for the study that became PCAST-97.

Process

The panel conducting the study consisted of 6 members of PCAST itself and 15 other panelists chosen to bring needed additional expertises and perspectives. Backgrounds of the panelists ranged across the full diversity of energy options and encompassed affiliations and experience in academia, nongovernmental organizations, electric utilities, other energy companies, and government energy and regulatory agencies. (To avoid awkwardness and ensure independence, no currently serving government officials were members of the panel.) About half a dozen members of the panel were not energy specialists per se. This faction included PCAST Co-Chair John Young (former CEO of Hewlett Packard), Massachusetts Institute of Technology President Charles Vest, and former Chair of the President's National

Economic Council Laura Tyson; it served to restrain any "energy cheerleading" tendencies of the energy specialists and to ensure that any recommendations for increased funding received critical scrutiny within the group.

The panel divided itself into four task forces matching the organization of applied-energy-technology R&D within the DOE: energy efficiency, fossil-fuel technologies, nuclear technologies, and renewable-energy technologies, chaired, respectively, by Maxine Savitz, William Fulkerson, John Ahearne, and Robert Williams. In addition, "cross cutting" working groups were formed to address such topics as the leverage of R&D in addressing the energy challenges of the twenty-first century, the recent patterns of public and private energy R&D spending in the United States and abroad (a group augmented by two members of Holdren's research group at Harvard, Paul de Sa and Ambuj Sagar, who wrote much of the corresponding chapter in the PCAST-97 report), the evolving roles and interactions of the public and private sectors in energy R&D, metrics for evaluating success and failure in energy R&D efforts, and issues in DOE management of its energy R&D portfolio.

From March through September 1997, the full panel met five times, usually for two days, and its task forces and other subgroups conducted numerous additional meetings and field trips. The full panel received briefings from all the relevant divisions of the DOE, which were then followed up by more in-depth interactions of DOE personnel with the corresponding task forces. Input was also solicited from many other members of the energy community in industry, academia, government, and public-interest organizations. Altogether the panel or its task forces met with some 250 energy experts and received detailed written inputs from some 30 more with whom it did not meet (2, Appendix A). Full advantage was taken of the work of the SEAB review of US energy R&D from two years earlier, with the help of having the vice chair and two other members of the SEAB study on the panel for this one.

Particularly contentious issues in the panel's deliberations included: the amount of emphasis to be given to the climate-change issue as a motivator of energy R&D needs; what to say about the future of the nuclear-fission option (R&D spending on which had fallen to a mere $42 million per year in the FY 1997 budget and $7 million in FY 1998); whether the government has a proper role, beyond R&D, in trying to encourage the commercialization of energy options offering large public benefits; what kinds of recommendations to make about the DOE's management; and, of course, what additions or cuts to recommend in the various energy-technology budget lines. Notwithstanding the difficulty of these issues and the history of disagreements about many of them across the energy community, the panel reached unanimous conclusions about all of them.

This success was partly a matter of having panelists who were able to listen as well as argue and who had the independence of mind to diverge, in the interests of logic and sensible compromise, from positions held by many within their constituencies. The unanimity in budget recommendations was also made possible, we think, by the panel's having escaped the imposition, in its charge, of an overall budget ceiling for its recommendations—e.g., to produce the best energy R&D portfolio possible for under $1.5 billion per year—which would have turned the exercise into a zero-sum game. Instead, the panel had the luxury of constructing a recommended portfolio from the bottom up, asking for each option what the appropriate level of federal R&D investment should be given the state of the field and its prospects, what the current and likely future role should be of the private sector in the option's development, and what the option's deployment would offer in terms of public benefits. (Some might think this would result in recommendations of funding increases in every area. To the contrary, in the end, a number of areas were recommended for cuts.) Each task force had to defend its budget recommendations before the full panel, whereupon the amounts agreed on were summed to get the portfolio total.

The study was completed more or less on schedule. A 33-page executive summary of findings—including the detailed budget recommendations developed as described above—was approved by the full PCAST on September 30, 1997, and transmitted to the President the same day (just before his October 1 deadline). The full report of some 270 pages was issued about a month later, in early November.

Content

The report began with an overview of the energy-linked economic, environmental, and national-security challenges faced by the United States as it moves into the twenty-first century, noting that (2, p. ES-1):

> Our economic well-being depends on reliable affordable supplies of energy. Our environmental well-being—from improving urban air quality to abating the risk of global warming—requires a mix of energy sources that emits less carbon dioxide and other pollutants than today's mix does. Our national security requires secure supplies of oil or alternatives to it, as well as prevention of nuclear proliferation. And for reasons of economy, environment, security, and stature as a world power alike, the United States must maintain its leadership in the science and technology of energy supply and use.

The report also noted at the outset that US interests in energy are closely coupled to what is happening in the rest of the world, above all in developing countries. The panel wrote (2, p. ES-1):

> The combination of population growth and economic development in Asia, Africa, and Latin America is driving a rapid expansion of world energy use, which is beginning to augment significantly the worldwide emissions of carbon dioxide from fossil fuel combustion, increasing pressures on world oil supplies, and exacerbating nuclear proliferation concerns. Means must be found to meet the economic aspirations and associated energy needs of all the world's people while protecting the environment and preserving peace, stability, and opportunity.

In addressing the rationale for federal government involvement in energy-technology innovation to help address these challenges, the panel stressed the large "public benefits" dimension of energy issues—the point that the interests of society as a whole in environmental quality, reliability of energy supply (in both its economic and national-security dimensions), meeting the basic energy needs of society's poorest members, and providing a sustainable energy basis for economic development considerably exceed the interests of private firms in these outcomes, as reflected in the returns they can expect to gain from investments in energy R&D. The panel also noted that a number of trends within energy industries themselves—such as deregulation, energy-sector and corporate restructuring, and increasing competitive pressures on the short-term "bottom line"—were evidently combining to reduce private-sector investment in energy R&D, above all those components of energy R&D entailing substantial risks or long time horizons.

Notwithstanding the force of these arguments, the panel recognized that the private sector has the dominant role in bringing advanced energy technologies into widespread use, that this will be even more true in the future than it has been in the past, and that, therefore, it is essential to shape the government's efforts in energy-technology innovation to complement and utilize the strengths of the private sector, not in any sense to replace them. The panel wrote, in this vein, that projects in the federal energy R&D portfolio (2, chap. 7, pp. 1–2) "should be shaped, wherever possible, to enable relatively modest government investments to effectively complement, leverage, or catalyze work in the private sector. Where practical, projects should be conducted by industry/national-laboratory/university partnerships to ensure that the R&D is appropriately targeted and market relevant, and that it has a potential commercialization path to ensure that the benefits of the public R&D investment are realized in commercial products." Although it had not been asked to address the possibility of government efforts extending beyond R&D in the direction of commercialization of advanced energy technologies, the panel offered an argument that the same public-benefits rationale supporting government involvement in energy R&D, combined with the existence of a variety of barriers to private-sector commercialization of some of the advanced energy technologies offering very large public benefits, does justify a degree of government engagement in promoting commercialization in particular circumstances. It wrote (2, p. ES-28): "After consideration of the market circumstances and public benefits associated with the energy-technology options for which we have recommended increased R&D, the panel recommends that the nation adopt a commercialization strategy in specific areas complementing its public investments in R&D. This strategy should be designed to reduce the prices of the targeted technologies to competitive levels, and it should be limited in cost and duration." The panel did not, however, propose either a magnitude or a source of funds for such a commercialization initiative, considering this too far beyond its mandate.

A particularly challenging issue for the panel, in addressing the rationale for government involvement in energy-technology innovation, was what to say about the role of the climate-change problem in this rationale. The panel was well aware of, and in complete agreement about, the wide range of potential benefits from energy innovation besides the possibility of more cost-effective approaches to reducing greenhouse gas emissions. It also recognized the political difficulty that its recommendations would encounter if they were perceived as purely a response to the climate issue. And the panel itself was hardly in complete agreement about all aspects of the climate issue. It chose to treat the issue by first summarizing, largely through direct quotation, the findings of the Second Assessment of the IPCC (25, 26), and then noting that a variety of views existed about how those findings should be interpreted (2, pp. 1–12): "Some members of the research community think the IPCC's projections of future climate change and its consequences are too pessimistic, while others think they are too optimistic. Some contend that adaptation to climate change would be less difficult and less costly than trying to prevent the change; others argue that a strategy combining prevention and adaptation is likely to be both cheaper and safer than one relying on adaptation alone. Within the PCAST energy R&D panel there are significant differences of view on some of these questions." These differences having been mentioned, the panel then spelled out three crucial propositions, on which it had been able to agree, about the role of the climate issue in energy R&D strategy (2, pp. ES-10 and ES-11):

- First, there is a significant possibility that governments will decide, in light of the perceived risks of greenhouse-gas–induced climate change and the perceived benefits of a mixed prevention/adaptation strategy, that emissions of greenhouse gases from energy systems should be reduced substantially and soon. Prudence therefore requires having in place an adequate energy R&D effort designed to expand the array of technological options available for accomplishing this at the lowest possible economic, environmental, and social cost.
- Second, because of the large role of fossil-fuel technologies in the current U.S. and world energy systems, the technical difficulty and cost of modifying these technologies to reduce their carbon dioxide emissions, their long turnover times, their economic attractiveness compared to most of the currently available alternatives, and the long times typically required to develop new alternatives to the point of commercialization, the possibility of a mandate to significantly constrain greenhouse gas emissions is the most demanding of all of the looming energy challenges in what it requires of national and international energy R&D efforts.
- Third (and this finally is the *good* news about the greenhouse gas issue), many of the energy-technology improvements that would be attractive for this purpose also could contribute importantly to addressing some of the other energy-related challenges that lie ahead, including reducing dependence on imported oil, diversifying the U.S. domestic fuel- and electricity-supply systems, expanding U.S. exports of energy-supply and energy-end-use technologies and know-how, reducing air and water pollution from fossil-fuel technologies,

> reducing the cost and safety and security risks of nuclear energy systems around the world, fostering sustainable and stabilizing economic development, and strengthening U.S. leadership in science and technology.

From its detailed review of the then-existing portfolio of applied-energy-technology R&D in the DOE, in the context of the rationales for government involvement as just described, the panel concluded that these programs "have been well focused and effective within the limits of available funding" but that they "are not commensurate in scope and scale with the energy challenges and opportunities the twenty-first century will present." It noted that "[t]his judgment takes into account the contributions to energy R&D that can reasonably be expected to be made by the private sector under market conditions similar to today's," and it argued that "the inadequacy of current energy R&D is especially acute in relation to the challenge of responding prudently and cost-effectively to the risk of global climate change from society's greenhouse-gas emissions" (2, p. ES-1). It recommended ramping up the DOE's applied-energy-technology R&D spending from the $1.3 billion level of the FY 1997 appropriation (and from the $1.4 billion level of the FY 1998 request, not yet acted on by Congress at the time the report was written) to about $1.8 billion in FY 1999, $2.0 billion by FY 2000, and $2.4 billion by FY 2003, with the largest increases going to energy efficiency and renewable energy.[7] Among the key findings and recommendations about the main classes of energy technologies were the following.

ENERGY END-USE EFFICIENCY The panel found particular promise in enhancements to energy-efficiency R&D, which it found could bring relatively rapid and cost-effective reductions in local air pollution and greenhouse gas emissions, oil imports, and energy costs for households and businesses. From 1975 to 1986, the panel noted, US energy efficiency increased by almost one third (measured as the ratio of real GNP to primary energy use); if the energy-intensity of the economy had remained constant from 1970 to 1997, by contrast, US energy expenditures in 1997 would have been some $150–200 billion per year greater than they actually were. The improvements in energy efficiency that were achieved helped pull the US economy out of the stagflation that followed the oil-price shocks of the 1970s, helped set the stage for sharply declining world oil prices, and gave the US economy more than a decade and a half of opportunity to deal with the energy problem (an opportunity that, regrettably, went largely unused). The panel found that investments in advanced energy-efficiency technologies—beyond those likely to be brought forth by the marketplace—offered the potential for further large gains in the future and recommended that the DOE's budget for energy-efficiency

[7]These figures are as-spent dollars and include budget authority for R&D in energy-end-use efficiency, fossil-fuel technologies, nuclear fission, nuclear fusion, and renewable energy. They do not include the Basic Energy Sciences category in the DOE's research budget, nor a number of other categories, often listed as part of "energy R&D" but not directly related to development of specific energy options for meeting civilian needs (see also Footnote 6).

R&D be doubled in constant dollars from the 1997 actual level of $373 million to $755 million in 2003 (which would be about $880 million in as-spent dollars, given inflation at the projected rates).[8]

The panel proposed a number of specific goals for efficiency-improvement efforts in the various end-use sectors, including: (*a*) development of the technologies for, and facilitating the construction by 2010 of, 1 million zero-net-energy buildings, and achievement in all new buildings of an average 25% increase in energy efficiency compared with new buildings in 1996; (*b*) development, with industry, of a 40% efficient microturbine by 2005 and a 50% efficient microturbine by 2010, initiation of new Industries of the Future programs in agriculture and bio-based renewable products, and reduction of the energy intensity of the major energy-consuming industries—forest products, steel, aluminum, metal casting, chemicals, petroleum refining, glass—by one fourth by 2010; and (*c*) cooperation with industry to achieve the goal, previously established under the Partnership for a New Generation of Vehicles, of developing an 80-mile-per-gallon production prototype passenger car by 2004, as well as working with industry to develop a production prototype of a 100-mile-per-gallon passenger car with zero equivalent emissions by 2010, high-efficiency (tripled fuel economy) class 1–2 trucks and (doubled fuel economy) class 3–6 trucks by 2010, and a high-efficiency (10 miles/gallon) heavy truck (class 7 and 8) by 2005. The panel concluded that, overall, "DOE research, complemented by sound policy, can help the country increase energy efficiency by a third or more in the next 15 to 20 years."

FOSSIL ENERGY TECHNOLOGY Fossil fuels supply more than three quarters of primary energy worldwide and 85% of primary energy in the United States,[9] and they will remain a mainstay of energy supply for many decades to come. Recognizing the very large size of the private sector's fossil-energy activities, including R&D, the panel emphasized restructuring the DOE's fossil-energy program toward activities with a higher public return. It recommended the phase-out of R&D on near-term coal power technologies because there was relatively less public benefit to be expected from furthering this work than was the case for longer-term coal-technology programs under way in the DOE—notably Vision-21 (28)—and because the market potential of these technologies was very limited, given the significantly lower cost of advanced gas turbine cycles fueled by natural gas.[10] Similarly, direct coal liquefaction was recommended for termination, on the grounds that it was not likely to be cost-effective in the foreseeable future, would

[8]These figures do not include weatherization, state and local grants, and other non-R&D activities funded by the DOE under the energy-efficiency budget lines.

[9]These percentages account for the estimated contributions, often left out of official tabulations, from the "traditional" biomass energy sources (fuelwood, charcoal, crop wastes, and dung). Without these, the fossil-fuel percentage contributions would appear even larger.

[10]The panel did not recommend cuts in R&D on pollution-control technologies for current or near-term coal power systems, however.

significantly increase emissions of carbon dioxide, and offered no synergies with other technologies under development—in contrast to indirect coal liquefaction, which uses gasification technologies that are also relevant to advanced power generation and other programs.

The panel recommended increased support, in the fossil-fuel sector, for the DOE's advanced power, carbon sequestration, fuel cell, hydrogen, and advanced oil and gas production programs, as these could increase the country's leverage against the greenhouse-gas/climate-change and oil-import problems, among others. The initiation of research on methane hydrates was also recommended, both to better evaluate the resource and to determine whether it could be tapped in the longer term to supplement conventional gas resources as a bridging fuel to low- or no-carbon energy systems. Continued support for advanced technologies for the low-cost recovery of oil and gas from lower margin resources was also recommended. Such programs have long been targets of government-spending critics concerned with "corporate welfare"; but the panel's review found that those who benefited were small companies with little ability to conduct research, that advanced approaches helped maintain domestic production, and that to close these wells without such recovery would effectively foreclose further production from them permanently.

The panel's review of fossil-energy issues also clarified and highlighted the importance, for US fossil-energy-technology R&D strategy, of international markets for these technologies. In the US electric-power sector, most new capacity in recent years has been in the form of natural gas–fired gas-turbine combined cycles, and this is likely to remain the case until natural gas prices experience sustained increases to levels that seem improbable in this country for some time to come. That would mean that the major markets for advanced coal-power technology will be outside the United States in the decades immediately ahead, above all in coal-intensive developing countries, such as China and India, where natural gas is in very limited supply. For the United States to maintain leadership in these technologies, they will need to be developed in forms suitable for those markets, and US companies will need to learn to operate successfully there. (More about this in connection with PCAST-99, below.)

Altogether, the changes recommended by the panel would have resulted in the DOE's fossil-energy R&D budgets staying roughly level in constant dollars from FY 1997 through FY 2003.

NUCLEAR ENERGY Energy from nuclear fission supplies about 17% of world electricity and 20% of that of the United States. But concerns about nuclear energy's cost, accident risks, radioactive-waste burdens, and potential links to nuclear proliferation have clouded its future. No new reactors have been ordered in the United States since 1978. Federal expenditures on R&D in fission energy, once as high as $2 billion per year in 1997 dollars, had fallen by FY 1997 to just $40 million (and dropped to $7 million in FY 1998). The panel concluded, however, that the potential role of an expanded contribution from nuclear energy in helping to address global carbon dioxide emissions justified a modest Nuclear Energy Research Initiative (NERI) to determine whether and how improved fission technologies might be able to address cost, safety, waste, and proliferation concerns. Whether or not such work led to a possibility of expanding nuclear energy's contribution in the United States, it would be useful in helping to maintain positive US influence over the safety and proliferation resistance of nuclear energy activities in other countries.

The panel recommended, accordingly, that DOE funding for nuclear fission should increase in constant dollars from $42 million in FY 1997 to $102 million in FY 2003 ($119 million in as-spent dollars in 2003). In addition to NERI, a small part of this funding—$10 million per year, to be matched by industry—would be used to investigate problems that otherwise might prevent the safe extension of the operating life of existing reactors. The NERI effort, in contrast to previous research efforts in the DOE's Nuclear Energy Program, would be organized as a competitive solicitation for investigator-initiated R&D focused on the indicated key issues affecting fission's future.

In the case of fusion energy, the panel endorsed the overall findings of the PCAST-95 study summarized above and recommended that DOE funding for fusion be increased from $232 million in FY 1997 to $281 million in 2003 in constant dollars ($328 million in FY 2003 in as-spent dollars). The panel affirmed that the guiding principles for the US fusion program should be maintaining a strong domestic base in plasma science and fusion technology, collaborating internationally on an experimental program for the next steps in ignition and moderately sustained burn, and participating in international efforts to develop practical low-activation materials for fusion energy systems.

RENEWABLE ENERGY Few people disagree with the premise of renewable energy—tapping natural flows of energy from the sun, wind, and other sources to produce environmentally clean, nondepletable energy for people's use; the problem has been the high cost of successfully capturing these diffuse flows of energy and converting them to the needed end-use forms. Over the past two decades, however, remarkable progress has been made. The cost of energy from such technologies as photovoltaics and wind turbines has dropped as much as ten times. Based on the outstanding progress that has been made, the high potential of renewable-energy technologies in every sector of the energy economy (electricity, fuels, and heat for buildings, industry, and transportation), and the high public benefits of achieving such contributions, the panel recommended that funding for the DOE's renewable-energy programs should be increased from $270 million in FY 1997 to $559 million in FY 2003 in constant dollars ($652 million in FY 2003 in as-spent dollars).

Priority areas identified by the panel for R&D increases included solar photovoltaics (particularly thin-film technologies and balance-of-system issues), advanced wind turbines (particularly light-weight, variable-speed designs), and bioenergy (especially integrated power-and-fuels systems), as well as solar thermal, geothermal, and hydrogen energy systems. As for much fossil and nuclear technology, the panel noted, international markets are critical for renewables. Roughly three quarters of US photovoltaics production is exported, and most of the wind-turbine market has likewise been outside the United States in recent years (domestic sales of wind turbines, however, increased sharply in 1998 and 1999). And the modularity and small scale of many renewable-energy technologies match well the needs of developing countries, particularly in rural areas. A further advantage in developing-country applications is that the inherent cleanliness and safety of most renewable-energy technologies minimizes the need for the complex regulatory controls that fossil- and nuclear-energy systems require.

OTHER RECOMMENDATIONS Besides the recommendations just summarized for the applied-energy-technology sectors in the DOE's portfolio, the panel made a number of recommendations that cut across those sectors. In addition to the recommendation about commercialization strategy, mentioned above, these included (*a*) increased coordination between the DOE's Basic Energy Sciences Program and its applied-energy-technology programs[11]; (*b*) more systematic efforts within the DOE at integrated assessment of its entire energy R&D portfolio "in a way that facilitates comparisons and the development of appropriate portfolio balance, in light of the challenges facing energy R&D and in light of the nature of private-sector and international efforts and the interaction of US government R&D with them" (2, p. ES-6); and (*c*) other improvements in the DOE's management of its energy R&D portfolio, including that the overall responsibility for the portfolio be assigned to a single person reporting directly to the Secretary of Energy and that increased use be made of industry/national-laboratory/university advisory and peer-review committees, while reducing internal process-oriented reviews. The panel also recommended strongly that increased attention be devoted to the opportunities for strengthening international cooperation on energy-technology innovation—a recommendation that became the basis for the subsequent PCAST study with this focus, discussed in detail below.

Impact

The PCAST-97 study was being completed as the Clinton administration was finalizing its preparations for the December 1997 Kyoto Conference of the Parties to the UN Framework Convention on Climate Change, where difficult negotiations on targets, timetables, and mechanisms for reductions in emissions of greenhouse gases were expected to (and did) take place. Although the PCAST study was focused on a wide array of benefits of energy-technology innovation, of which reducing greenhouse gas emissions was only one, and although it made no recommendations at all about targets and timetables for such reductions, it underlined the role of technological innovation in making sustained reductions possible, and its recommendations about energy R&D strategy were of immediate interest to those engaged in shaping that element of the administration's climate-change package.

[11]The PCAST-97 study did not review the content of the Basic Energy Sciences (BES) Program, but it did recommend, in light of the close coupling between advances in BES and progress in the applied-energy-technology R&D, that the DOE consider expanding its BES effort in parallel with the recommended increase in applied-energy-technology work and the proposed increase in coordination (2, p. ES-2).

The completion of the executive summary and its endorsement by the full PCAST at the end of September 1997 was therefore followed by a spate of briefings for officials in the DOE, the Office of Management and Budget, and the Council of Economic Advisors, among others, and its findings quickly entered administration discussions about climate policy and about the administration's energy R&D budget request for FY 1999. Also salient in these discussions were two other studies completed in 1997: the five-NGO study conducted by the Alliance to Save Energy and four other US-based NGOs (29); and the five-lab study conducted by the Lawrence Berkeley National Laboratory and four other DOE labs (30).

The climate policy announced by President Clinton on October 22 included an energy-technology R&D initiative, concerning which the supporting papers cited the PCAST study (31). This Climate Change Technology Initiative (CCTI), which embodied a substantial fraction of the energy R&D increases that PCAST had recommended, was incorporated into the administration's FY 1999 budget request. Increases in energy-technology R&D over the five-year period covered by the CCTI proposal would have added up to $2.7 billion, compared with increments totaling about $4.3 billion over this five-year period in the PCAST package.[12] The administration's budget request for FY 1999 contained an increment of $330 million over the FY 1998 appropriation—about two thirds of the $490 million increment recommended for FY 1999 by PCAST.[13]

Subsequent to transmittal of the budget request to Congress, PCAST energy panelists made numerous visits to members of the relevant congressional committees and their staffs to argue for the increases the administration had requested. The CCTI label proved to be a handicap in this, as some Republican legislators were reluctant to support what appeared to them to be "Al Gore's climate agenda."[14] Nonetheless, Congress appropriated about 55% of the overall increment the administration had requested, so the FY 1999 applied-energy-technology R&D appropriation ended up about $180 million larger than in FY 1997 and FY 1998.

Table 1 shows the distribution across the energy sectors of PCAST's recommended budgets, the administration's requests, and the congressional appropriations for FY 1999, FY 2000, and FY 2001, along with the appropriations from FY 1998 and the PCAST recommendations for FY 2002 and FY 2003. These figures show that the requests and appropriations have continued to rise, through 2001, in

[12]In addition to the indicated R&D increases, the climate policy announced on October 22 also contained a package of tax credits intended to encourage deployment of the best-available low–greenhouse gas–emitting energy technologies, amounting to $3.6 billion over the five-year period.

[13]The discrepancy was not evenly distributed across the energy sectors: Fossil energy received somewhat more money under the request than PCAST recommended, renewables and efficiency considerably less. See Table 1.

[14]Some called the package "premature implementation of the Kyoto Protocol," which had been signed in December 1997 but not submitted to the Senate for ratification. In reality, however, that protocol is focused on targets and timetables for emissions reductions, and energy R&D expenditures do not entail any such commitment; they merely would make it easier to achieve any commitment to which the country eventually decided to agree (32).

TABLE 1 Federal energy technology R&D: congressional appropriations, administration requests, PCAST recommendations[a]

	Efficiency	Renewable	Fossil	Fission	Fusion	Total
FY 1998 appropriation	437	272	356	7	223	1295
FY 1999 appropriation	503	336	384	30	222	1475
Administration's request	598	372	383	44	228	1625
PCAST recommendation	615	475	379	66	250	1785
FY 2000 appropriation	552	310	404	40	250	1559
Administration's request	615	398	364	41	222	1640
PCAST recommendation	690	585	406	86	270	2037
FY 2001 appropriation	600	375	433	59	255	1722
Administration's request	630	410	376	52	247	1715
PCAST recommendation	770	620	433	101	290	2214
FY 2002						
PCAST recommendation	820	636	437	116	320	2329
FY 2003						
PCAST recommendation	880	652	433	119	328	2412

[a]In as-spent dollars. Notes: The values listed here may vary from other listings because of rescissions, uncosted obligations, inclusion or exclusion of other budget lines, and other factors. The efficiency line listed here does not include state and local grants or the Federal Energy Management Program. The nuclear fission line includes only direct civilian energy-related R&D (Nuclear Energy Research Initiative, NEPO, Nuclear Energy Plant Optimization program, etc.) and university training support. The fossil-energy line does not include expenditures for the clean-coal program.

a pattern similar to that recommended by PCAST, but at a slower pace and with a particularly conspicuous shortfall in the renewable category.

Notable instances of progress (or the lack of it) under the post–FY 1998 budgets on issues addressed by the PCAST-97 report include the following.

END-USE EFFICIENCY The administration launched in 1998 the Partnership for Advancing Technology in Housing, based in part on discussions with industry begun in 1994, which aims—with strong private-sector participation—to achieve an average 50% increase in energy efficiency in new homes by 2010. In concert with industry, the DOE has launched an Industries of the Future Program for agriculture, building on the DOE's success using this model in other industries. The Partnership for a New Generation of Vehicles (PNGV), which predated the PCAST report, continues on track—the major participating automobile companies all demonstrated prototype vehicles in early 2000—but a PNGV-2 focused on longer-term options, such as fuel cells, has not been initiated. The Twenty-First Century Truck initiative was launched in spring 2000, with goals of doubling to tripling the fuel economy of trucks on a ton-mile basis. Activities in microturbines, fuel cells, and combined heat and power have been strengthened.

FOSSIL FUELS The direct–coal-liquefaction program has been phased out and near-term clean-coal-power–technology R&D has been reduced. The Vision-21

Program, which predated PCAST-97, to develop cost-competitive coal-fired power plants with low or no carbon or polluting emissions has been strengthened. Geological carbon sequestration and methane hydrate R&D programs have been launched.

NUCLEAR FISSION The administration launched and Congress funded both the Nuclear Energy Plant Optimization Program (addressing issues related to license extension) and the Nuclear Energy Research Initiative (addressing the longer-term issues that will shape fission's future). These two initiatives form the basis of the current DOE Nuclear Energy Program.

NUCLEAR FUSION Administration requests at $243 million and congressional appropriations at $255 million for FY 2001 have started to move in the direction, but still fall short, of the PCAST recommendation of $290 million (as-spent dollars) for fusion energy in FY 2001.

RENEWABLES Administration budget requests and program direction have largely aligned with PCAST recommendations, but at lower funding levels, and appropriations have been well below the requests (even falling from FY 1999 to FY 2000 before recovering somewhat in FY 2001). With strong bipartisan support (33), the President issued Executive Order 13134 (34), which launched an integrated bioproduct, biofuel, and biopower program with a goal of tripling US bioenergy use by 2010. Congress passed and the President signed the Agricultural Risk Protection Act of 2000, Title III of which codified an integrated bioproduct and bioenergy research program. Principal focuses of increased renewables funding other than for biomass were for photovoltaics and advanced wind systems.

CROSS-CUTTING ISSUES Since the PCAST study, the DOE has undertaken a major effort in integrated analysis of the department's entire energy R&D portfolio, which reaffirmed the overall direction of the program while highlighting some key gaps, including energy-system reliability and international energy (35, 35a). The DOE has also made considerable effort at, and progress in, addressing its management challenges, which were pointed out not only in the PCAST-97 report but also in the 1995 SEAB study (6) and a 1999 review by the National Academy of Public Administrators (36). The risk remains, however, that there will be excessive emphasis on process to the detriment of substance. The critical question raised by PCAST about a role for government in the commercialization of high–public-benefit energy technologies, moreover, has not been addressed by the DOE or, more important, by Congress.

Of course, some of the progress that has occurred in the government's energy R&D programs since the publication of PCAST's recommendations would have occurred in any case. Similar recommendations were made or implied in some instances by other studies appearing in the same general time period (6, 29–31, 36) or in the DOE's own internal reviews. But it does seem fair to assume that the combination of the comprehensiveness and detail of the PCAST-97 recommendations, the diversity and respectability of the panel that unanimously agreed on them, and the effort devoted by the panel to promoting its findings within the DOE and with other policy makers subsequent to the report's release had some significant influence on these outcomes.

PCAST-99—POWERFUL PARTNERSHIPS: THE FEDERAL ROLE IN INTERNATIONAL COOPERATION ON ENERGY INNOVATION

In communications with the President about energy strategy following completion of the PCAST-97 report and the conclusion of the contentious Kyoto climate conference at the end of the same year, PCAST stressed the likely need, in the longer term, for far larger reductions in greenhouse gas emissions than those discussed in Kyoto, and it emphasized that advanced energy supply and end-use technologies would be indispensable in achieving such reductions (37). PCAST also pointed to the need for international cooperation if emissions were to be reduced significantly below business-as-usual trajectories not just in the advanced industrial nations but in transition and developing economies as well, as would be necessary to stabilize the atmospheric carbon dioxide concentration; and it noted the benefits of such cooperation for a variety of other economic, environmental, and security interests of the United States.

These arguments reinforced the PCAST-97 recommendation that increased attention be given to international cooperation on energy-technology innovation. In response, in July 1998, President Clinton directed his Science and Technology Advisor (then Neal Lane, who succeeded John H. Gibbons in this capacity on the latter's retirement) "to work with the National Science and Technology Council (NSTC) agencies, industry, universities, other organizations, and with PCAST to review the US international energy R&D portfolio and to report to me by May 1, 1999, on ways to improve the US program of international cooperation on energy R&D to best support our nation's priorities and address the key global energy and environmental challenges of the next century" (38). Lane (39) then directed that PCAST form an international energy R&D panel to assist him in this assignment, and gave it the following specific charges:

Challenges. Identify the key energy-linked challenges facing the United States and the world in the first several decades of the 21st century and analyze their implications with respect to national and global economic vitality, local and global environmental quality, and national security.

U.S. Experience. Provide a synopsis of international energy R&D experience within the principal U.S. agencies, with particular attention given to the lessons that have been learned and their implications for the design and operation of future activities.

Foreign and Multilateral Public and Private Experience. Review foreign bilateral and multilateral public and private international energy R&D activities, examine their strategic role in meeting national goals, and identify the key lessons for U.S. international energy R&D activities.

R&D Opportunities. Identify important international energy efficiency, renewable, fossil, and nuclear energy technology R&D opportunities and their associated budget and programmatic requirements within a balanced R&D portfolio that would make the U.S. role more responsive to the global energy-linked challenges of the next several decades.

Deployment. Identify innovative mechanisms for large-scale publicly-leveraged market-driven deployment of advanced energy technologies. Examine the relationships between R&D cooperation and international market competition in international energy programs. Evaluate experience with institutional learning in the R&D and deployment of advanced energy technologies and synthesize the lessons learned. Identify factors that limit the effectiveness of public R&D and deployment efforts.

Strategic Framework. Develop a strategic framework and action agenda that could help meet national and global challenges through international energy R&D and identify collaborative and competitive components.

It is notable that these terms of reference specifically requested—in contrast to the mandate for PCAST-97—that the study look beyond R&D to mechanisms for accelerating the deployment of advanced energy technologies. This change reflected growing recognition that demonstration and deployment issues are tightly linked to R&D and warrant appropriate government attention in cases where a technology's expected social benefits exceed the private ones (as the PCAST-97 report had argued).

Context

At the time, in late 1998, when the study that became PCAST-99 was getting organized, a panoply of factors was combining to generate increased US public and policy-maker interest in the international dimensions of energy issues. The two most important such factors were, first, the growing concern about global climate change and its potential implications for energy strategy and, second, the rapid rise in the share of US oil consumption derived from imports.[15] In addition, it was recognized at least by specialists that most of the growth in global energy use in the twenty-first century would almost certainly take place in the developing countries, which were on a course to pass the industrialized nations as energy users

[15]US oil imports were 30% of consumption in 1982 and 1983, having fallen from a previous all-time high of 49% in 1977, but by 1994 the figure had climbed again to 50% and in 1998 it was to be over 55% (40). OPEC's share of the world oil-export market had reached 62% by 1998, and that of the Persian Gulf was 43%.

sometime between 2015 and 2025. And much of the developing-country growth would come, under business-as-usual conditions, from increased use of coal and increased imports of oil. All this meant that as the century wore on, the challenge of reducing greenhouse gas emissions would increasingly depend on what happened in developing countries; that pressure on world oil supply and the associated potential for conflict over access to oil would increasingly depend, as well, on the extent to which developing countries would be able to deploy domestic alternatives to imported oil; and that the multi-hundred-billion-dollar-per-year global market in energy-supply technologies would be shifting increasingly to the South.

These trends and their implications were portrayed with particularly compelling clarity in a major study of alternative global energy futures cosponsored by the World Energy Council and the International Institute for Applied Systems Analysis, which was published in book form in 1998 (41). That study noted that all tolerable energy futures will require large infusions of energy-technology innovation worldwide, in order to make available the level of energy services required for prosperity without entraining unacceptable monetary, environmental, or political costs. The study also caught the attention of US and other industrial-country energy-technology manufacturers with its projection of cumulative developing-country investments in such technology of 5–7 trillion 1997 dollars between 1990 and 2020 and 10–20 trillion 1997 dollars between 2021 and 2050.[16]

Related to the immense potential of this developing-country energy-technology market, which was coming into clearer view in the late 1990s, was the ongoing process of energy-sector reform and deregulation under way then (and now) in many parts of the world, including many countries in the South. This trend was increasing the attractiveness of these markets for mainstream industrial-country energy-technology manufacturers and private financial institutions, leading to a growing private-sector role in North-South energy-technology transfer and cooperation, relative to official development assistance and government initiatives.

This did not mean an impending end to the roles of governments and multilateral development banks in developing-country energy sectors, however. As argued in the PCAST-97 study for the case of the United States domestically, the national- and global-level public-goods and externality issues attached to the energy sector mean that leaving it entirely to the private sector would be a major mistake. But it was becoming increasingly widely understood in the late 1990s that the private sector would be the dominant player in the evolution of the global energy system, and that government initiatives needed to be complementary to private-sector activities and sharply focused on preserving and enhancing public benefits.

Notwithstanding the good case that could and had been made for federal government initiatives conducted in concert with the private sector and focused on enhancing public benefits in the energy system, the receptiveness of the US Congress to funding such initiatives was low. Concerns frequently expressed in the Congress about international cooperation on energy technology included the notions that

[16]These investments are for energy supply and do not include energy end-use equipment.

this would constitute a giveaway of US technology and competitive advantage, that such programs are inevitably compromised by corruption, incompetence, and bureaucracy in the recipient countries, and that they amount to "corporate welfare," in which the government pays for activities that the private sector would otherwise be willing to pay for itself.

Process

The Panel on International Cooperation in Energy Research, Development, Demonstration and Deployment (ERD^3) formed to conduct the PCAST-99 study had 14 members: four chosen from the members of PCAST itself and ten picked for their relevant specialized expertise. In terms of the energy backgrounds represented and the public- and academic-sector versus private-sector distribution, however, the panel was hardly less diverse than the 21-person PCAST-97 panel. But like the two earlier PCAST energy panels, this one again managed to reach unanimous conclusions.

The greater scope of the subject matter—the activities of several agencies rather than of the DOE alone,[17] activities carried out in numerous countries rather than just in the United States, a focus extended to cover not only research and development but also demonstration and deployment—combined with the smaller panel and similarly compressed timescale meant that gathering the relevant information and arriving at recommendations in the time available was an even bigger challenge than had been the case with PCAST-97. The panel divided itself into task forces, each assigned to draft one of the final report's six chapters, but further mobilization and division of labor was needed and was achieved by commissioning from the RAND Corporation a study of the FY 1997 budget "baseline" of federal support for international cooperation on energy-technology innovation (42), by soliciting a dozen commissioned papers from an array of internationally known specialists in topics of particular relevance to the study (43–55), and by borrowing additional expertise from a related program directed by one of us at Harvard University and from the staff of the OSTP.[18] The panel received briefings and written submissions from more than 100 additional individuals.

[17]In addition to the DOE, significant activities in international cooperation on energy technology are carried out under the auspices of or affected by the policies of the US Agency for International Development, the Department of Commerce, the Department of State, the Department of the Treasury, the Environmental Protection Agency, the U.S. Trade and Development Agency, the U.S. Export-Import Bank, and more.

[18]Paul de Sa of the Kennedy School of Government wrote much of the chapter on "The International Landscape of ERD^3" (3). Insight about the role of NGOs in international energy cooperation came from a policy analysis exercise carried out by Meredith Tirpak for her 1999 Master of Public Policy degree from the Kennedy School. Particularly important contributions from the OSTP side came from Rosina M. Bierbaum, associate director of OSTP for Environment; Ann Kinzig, AAAS Roger Revelle Fellow in OSTP; and Martin Offutt, NSTC.

The 200-plus page PCAST-99 report (3) was transmitted to Presidential Science and Technology Advisor Neal Lane on May 24, 1999. OSTP prepared a six-page synthesis for distribution and briefings on the report were presented to the President's Chief of Staff and the Director of the Office of Management and Budget; the Secretary, Undersecretary, Deputy Secretary, and several Assistant Secretaries of Energy; the Undersecretary of State for Global Affairs; the outgoing and incoming heads of US Agency for International Development (USAID) and their principal deputies; the relevant officials in the Department of Commerce and the US Trade and Development Agency; and many other government officials. As with the preceding PCAST energy report, a sizable number of members of Congress and their staffs were also briefed on it.

Content

In making the case for federal support for international cooperation on energy technology, the PCAST-99 panel noted that many of the aspects of the energy problem with the largest public-goods and externality dimensions are inherently global in character, not adequately addressable by any single country or subset of countries. It argued that accelerated energy-technology innovation abroad and US participation in achieving this would benefit the United States by (*a*) reducing pressure on world oil supplies and the associated economic, political, and security risks of high costs of oil and access to it; (*b*) improving nuclear energy systems, on whose safety and proliferation resistance the whole world depends; (*c*) reducing other countries' contributions to global air pollution and greenhouse gas emissions; (*d*) providing the energy basis for politically stabilizing economic development and, with it, increasing opportunities for trade; (*e*) enhancing US access to increasingly global sources of innovation, both increasing the pace and lowering the cost of innovations for applications in the United States; and (*f*) bringing US firms access to and understanding of the multi-hundred-billion dollar-per-year foreign markets for energy technologies. The panel found, further, that not only these specific US interests but also "basic US values—respect for human dignity and human rights, belief in equity and opportunity, commitment to assistance for the least fortunate and to stewardship for future generations and for the environment—dictate US leadership in international cooperation on energy innovation for sustainable development" (3, p. ES-2).

The panel reported that the federal expenditures on international cooperation on ERD[3] in FY 1997 uncovered by the RAND study it had commissioned added up to about $235 million, of which 35% was for nuclear fission (mostly to improve the safety of nuclear reactors in Eastern Europe and the former Soviet Union), 25% was for nuclear fusion (mostly for ITER), 6% each went to renewable- and fossil-fuel technologies, 16% went to broad electricity-related activities, including electrical end-use efficiency, and 12% was not categorizable by fuel or end-use form. About 57% of this funding passed through the DOE, 40% through USAID, and the remainder through the Environmental Protection Agency and the Nuclear Regulatory Commission.[19]

Evaluating these activities against the needs and the opportunities, taking into account the relevant activities of the private sector, other governments, and multinational institutions, the panel found that they were "generally well focused and effective" but "inadequate in relation to the opportunities and insufficiently coordinated." The panel concluded, further, that there was "neither an over-arching strategic vision integrating and ensuring the comprehensiveness of the array of Federal activities on international energy RD^3 cooperation nor a mechanism for implementing such a vision in a coherent and efficient way" (3, p. ES-5).

The panel recommended initiatives in four categories—(*a*) foundations of energy innovation and cooperation, (*b*) energy end-use efficiency, (*c*) energy-supply technologies, and (*d*) management of the government's activities in support of ERD^3 cooperation—intended to "narrow the gap between the Federal programs that exist and the needs they seek to address" (3, p. ES-5). It recommended funding for this package at $250 million in FY 2001 and ramping up to $500 million in FY 2005, and it stressed that "these figures are intended to be supplemental to existing budgets for international ERD^3 activities and to the budgets proposed in the 1997 PCAST study for domestic energy R&D programs" (3, p. ES-5). It also noted that all the government's initiatives in ERD^3 should be "designed to be limited in the rate and duration of the government's investment, with specific criteria for terminating projects that fall short and for handing off successful ones to the private sector" (3, p. ES-4). The ingredients to which the panel assigned highest priority under the four headings were as follows.[20]

FOUNDATIONS OF INNOVATION AND COOPERATION The proposed initiatives in this category, accounting for $120 million of the $250 million FY 2001 package, fell under the headings of capacity building, energy-sector reform, energy-technology demonstration and cost buy-down, and financing. These initiatives were based on the need (*a*) to provide skilled labor that could support effective markets and institutions as well as the development and deployment of advanced energy technologies; (*b*) to help energy markets work effectively, encouraging mobilization of private capital; (*c*) to systematically lower the risks and costs of advanced energy

[19]The RAND survey was limited to the four indicated agencies. The panel found that about $1 billion of the US Export-Import Bank's FY 1997 lending was for energy projects, as was nearly $1 billion of the insurance and financing provided by the Overseas Private Insurance Corporation. US Trade and Development Agency investments in energy in FY 1997 were about $7.5 million. No estimates were obtained for relevant Department of Commerce and Department of State expenditures.

[20]The report includes additional recommendations that the panel considered important but of lower priority than those mentioned here. The indicated budget increments were intended to cover these additional "important" recommendations as well as the "high priority" ones.

technologies, accelerating market penetration; and (*d*) to facilitate finance for advanced energy technologies where existing financial mechanisms were inadequate, particularly for energy-efficiency and renewable-energy technologies and especially in rural areas.

With respect to capacity building, the recommendations included increased support for regional centers of RD^3 on sustainable energy options in Africa, Asia, Latin America, and Eastern Europe and the former Soviet Union, as well as expansion of in-country technical, managerial, entrepreneurial, and analytical training programs on energy.

The recommendations under energy-sector reform were "designed to support and shape energy-sector reform and restructuring—moving towards open competitive markets with improved financial performance—while retaining incentives for energy-technology innovations that address public goods and externalities" (3, p. ES-6). Recommended measures included (*a*) technical and policy advice on "getting prices right" through elimination of price controls and subsidies for conventional energy sources and through internalizing environmental costs and externalities, and on the creation of Public Benefits Funds (through, for example, nonbypassable fees on energy transmission and distribution services) to provide resources for advancing public benefits in restructured energy sectors, and (*b*) assistance in establishing regulatory frameworks for natural gas.

The recommendations under energy-technology demonstration and cost buydown were developed to "facilitate the demonstration, in foreign contexts, of advanced energy technologies with significant public benefits and to provide the means to 'buy down' to competitive levels the costs of technologies in this category that have learning-curve characteristics making this practical" (3, p. ES-7). The recommended measures included providing assistance in establishing a Demonstration Support Facility that would channel private-sector as well as public-sector funds into competitively selected demonstration projects, awarding energy-production tax credits to US firms participating in overseas demonstration projects meeting appropriate criteria, and helping to establish competition-based buy-down programs (such as auctions for specified contributions from targeted technologies) to move innovative technologies down the learning curve.

The recommendations on financing were aimed at helping to overcome some of the barriers to adequate flows of private capital into "clean and efficient energy technologies in developing and transition economies" (3, p. ES-7). They included measures to encourage support by the World Bank and other multilateral development banks for innovative as opposed to conventional energy technologies (which increasingly are and ought to be funded by the private sector), as well as for creation of a fund through the US Overseas Private Investment Corporation to facilitate market-based finance of clean-energy projects through highly leveraged partial credit guarantees.

ENERGY END-USE EFFICIENCY Recommendations in this category, accounting for $60 million of the $250 million FY 2001 package, were designed to accelerate the development and use of energy-efficient technologies in the buildings, industry, and transportation sectors. Efficient use of energy can usually reduce the total system-wide cost of providing energy services and can also be an intrinsic part of modernizing the economy, a feature particularly attractive to developing countries.

In the buildings sector, aiming at "reducing energy use in new appliances, homes, and commercial buildings in developing and transition economies by 50 percent over the next two decades compared to current performance" (3, p. ES-8), the panel recommended the following: (*a*) technical and policy assistance for the development and implementation of efficiency standards, ratings, and/or labeling of building equipment; (*b*) development, distribution, and training in the use of building-design software that minimizes energy use while enhancing building livability, and development and implementation of building energy codes and standards; and (*c*) encouragement of support of these measures through the grant and lending programs of the Global Environment Facility, the World Bank, and other multilateral financing institutions.

The industrial-sector recommendations had the stated aim of "engaging US industry in partnerships to reduce the energy intensity of major energy-using industrial processes in key developing and transition countries over the next two decades by 40 percent compared to their current performance" (3, p. ES-9). Recommended measures here included the development of "technology roadmaps" to identify and implement more productive and energy-efficient industrial processes; support for training, technical exchanges, and other human-capacity development; and matchmaking in joint venture development, technology licensing agreements, and other mechanisms to facilitate technology transfer between US firms and their partners.[21] The panel also recommended an aggressive outreach program to promote the use of combined-heat-and-power technologies for new power supply, including information and education programs, technical workshops, collaborative assessment of opportunities, and technical and policy support to address regulatory and market barriers.

Recognizing that US-based RD^3 on advanced automobiles (such as the Partnership for a New Generation of Vehicles) will quickly be commercialized globally, the panel focused its recommendations for improving the efficiency of transportation systems on RD^3 of low-cost, clean, energy-efficient buses and two- and three-wheeled vehicles. Support for the implementation of emissions standards and vehicle testing was also recommended.

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[21]Of some sensitivity here is the risk that improving the performance of basic industries in other countries might make them more competitive vis-à-vis US producers. The partnership approach recommended by the panel would minimize this risk, however. In addition, these other countries are building new plants and equipment to meet rapidly growing demand, which provides partnering US firms with more opportunities to experiment with new production technologies than would be available in the relatively stagnant US markets for energy-intensive materials. This could lead to lower production costs in the United States and increase the competitiveness of US producers.

ENERGY-SUPPLY TECHNOLOGIES The panel's recommendations under this heading, accounting for $70 million of the $250 million FY 2001 package, were divided into clusters addressing renewable-energy technologies, fossil-fuel decarbonization and carbon sequestration, and nuclear fission and fusion.[22] These initiatives focused on accelerating the introduction and use of advanced clean-energy supplies.

Recommended focuses in the renewable-energy sector included RD^3 on industrial-scale biomass conversion to multiple coproducts (chemicals, fuels, power, heat), on integrated renewable-energy and renewable-fossil hybrid systems, and on regional renewable-resource assessments.

The fossil-energy recommendations focused on RD^3 activities building on the DOE's Vision-21 Program (which is developing advanced integrated-gasification/combined-cycle and solid-oxide fuel-cell systems for coal with near-zero polluting and greenhouse gas emissions), with emphasis on producing multiple products from syngas derived from fossil and biomass feedstocks, on producing hydrogen from carbonaceous feedstocks while facilitating the recovery of byproduct CO_2 for ultimate disposal, and on advancing CO_2 sequestration through development of standards and the conduct of assessments and demonstrations.

Panel recommendations for nuclear energy included addition of an explicitly international component to the Nuclear Energy Research Initiative—focused on cost, safety, waste management, and proliferation resistance for fission energy systems—that had been proposed in the PCAST-97 report. Also included were expanded international cooperation on interim storage and geologic disposal of nuclear wastes and, consistent with the PCAST-95 report, "pursuit of a new international agreement on fusion R&D that commits the parties to a broad range of collaborations on all aspects of fusion energy development, while selectively enhancing US participation in existing fusion experiments abroad and inviting increased foreign participation in new and continuing smaller fusion experiments in the United States" (3, p. ES-11).

MANAGEMENT The panel recommended that the President establish an "Interagency Working Group on Strategic Energy Cooperation" in the National Science and Technology Council—with an advisory board drawn from the private, academic, and NGO sectors—to further develop and promote a strategic vision, provide ongoing assessment of the federal portfolio of international energy RD^3 activities, and assist agencies in their internal and external monitoring and review of projects. It recommended further that the agencies strengthen their internal

[22]In energy supply as well as in end-use efficiency, the panel's emphasis was less on developing entirely new technologies than on facilitating the adaptation and transfer of those already under development in the United States into developing-country contexts. This approach leverages existing US-focused ERD^3 investments into much wider application at modest additional cost.

management of international energy RD^3 activities through increased use of competitive solicitations for the activities—with a well developed business plan for moving technologies from research through to deployment a requirement for winning—and through establishment of clear, accountable management chains with the necessary authorities and budgets to implement the activities. It also recommended strengthening the international capabilities of the relevant agencies through "training, targeted hiring, and rotating national laboratory staff and outside academic and industrial technical experts through the agencies on a systematic basis, giving these persons senior professional status for guiding program planning and policy" (3, p. ES-12). Finally, the panel recommended that the government's funding for international energy-technology cooperation be "multi-year in duration in most instances, to diminish the influence of annual funding cycles on project selection and continuation and to promote the continuity of commitment that has often been lacking in US international-cooperation efforts" (3, p. ES-12).

Impact

In a decision memorandum of mid-September 1999, President Clinton responded favorably to the PCAST-99 recommendations, calling specifically for formation of an interagency working group within the National Science and Technology Council and for the development of international ERD^3 budget recommendations for consideration in the administration's FY 2001 request. He wrote (56):

> The report of the President's Committee of Advisors on Science and Technology (PCAST), *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation*, will help advance my Administration's goals for addressing energy-linked economic, environmental, and security challenges. As you point out in the synthesis of the report, our window of opportunity for moving the world off of its current energy trajectory—which entails higher consumer costs, greater regional pollution, more pronounced climate disruption, and increasing risks to energy security—is closing fast. Thus, we should act expeditiously on PCAST's recommendations for strengthening capacities for energy technology innovation, promoting technologies to limit energy demand and for a cleaner energy supply, and improving management of the Federal international energy research and development portfolio . . . . As a first step, I direct you to form a working group on international energy research, development, demonstration, and deployment under the National Science and Technology Council, as recommended by PCAST. The working group should build on the PCAST report and assess the portfolio of programs underway in the Federal agencies and develop a strategic vision, including budget recommendations that can be considered in agency requests for FY 2001.

A high-level working group was duly formed[23] and met several times in late 1999 and early 2000 in the course of conducting a bottom-up review to identify specific activities that were aligned with the needs identified in PCAST-99, that built on and leveraged, at low cost, existing US domestic R&D investments, and that formed a coherent and integrated set of activities linked across agencies. The decision of the administration during the fall of 1999 to stay within budget caps irrespective of budget surpluses significantly constrained what could be recommended, however. As a consequence, the recommendations that emerged were focused mainly on electricity supply and demand.

The resulting $100 million International Clean Energy Initiative (ICEI) was unveiled with the FY 2001 budget request in February 2000 (57).

The technology-development elements of the ICEI incorporated both electricity-supply and -demand components. On the supply side, proposed fossil-energy activities included RD^3 to accelerate Vision-21 technology development for international markets, transfer of best practices for coal-fired power plants and for combined heat and power; and RD^3 on methane leak reduction in oil and gas operations. The work on methane leak reduction was estimated to be able to reduce greenhouse gas emissions by the equivalent of as much as 100 million tons of carbon per year by developing and applying technologies to seal roughly 1 trillion cubic feet per year of methane leaks from Russian gas pipelines. The proposed nuclear energy activities focused on the extension of NERI R&D to the international community. Renewable-energy activities proposed included assessing renewable resources and accelerating RD^3 of biomass, photovoltaic, and wind energy systems. On the demand side, proposed RD^3 activities included adapting US whole-building energy-design tools to diverse country conditions; providing technical assistance in developing building and appliance energy codes and standards; providing technical assistance in industrial best practices; assisting development of national test facilities and programs; and training users in design tools, developers in codes and standards, and staff in testing. Total proposed funding for the supply and demand activities, above the FY 2000 baseline, was $40 million at the DOE and $8 million at USAID.

In addition, the ICEI proposed market-opening activities, including technical and policy support for energy-sector reform toward open competitive supply markets while protecting the public interest in innovation, environmental protection, and assisting the poor and rural areas; for removal of legal, regulatory, permitting, and market barriers to energy efficiency and renewable energy; for training and

[23]Chaired by OSTP associate director Rosina M. Bierbaum, it included representatives from relevant National Science and Technology Council (NSTC) agencies (the Departments of Energy, Commerce, State, and Treasury, and the Environmental Protection Agency), non-NSTC agencies (the US Agency for International Development and the trade agencies—the Export-Import Bank, the Overseas Private Investment Corporation, and the Trade and Development Agency), and several White House offices (the Office of Management and Budget, the Council of Economic Advisors, the Climate Change Task Force, and the Office of Science and Technology Policy).

capacity building; and for codes and standards development. Technical, policy, and regulatory assistance was also included for the Asian-Pacific Economic Council region to aid the development of evolutionary regulatory frameworks for natural gas infrastructure and thereby increase private capital formation for gas development. And technical assistance was proposed to strengthen nuclear regulatory institutions abroad. Total proposed funding for these activities, above the FY 2000 baseline, was $22 million at USAID and $3.5 million at the DOE.

Finally, the ICEI proposed a series of activities to assist US firms to sell their clean-energy technologies abroad. These measures included technical assistance and support for prefeasibility and feasibility analyses of projects—building on the existing Trade and Development Agency's program; expanded financial assistance through the Export-Import Bank; and expanded trade support through trade missions, trade conferences, and other information exchange and matchmaking. Also included in the package was support to extend proven US activities, such as Energy Star labeling and Energy Savings Performance Contracting. Total proposed funding for these activities, above the FY 2000 baseline, was $15 million at the Export-Import Bank, $5 million at the Trade and Development Agency, $4 million at the Department of Commerce, and $2.5 million at the DOE.

Congressional response was mixed at best. Although many members expressed strong support for the ICEI, the funding ultimately appropriated was only about $8.5 million, compared with the administration request of $100 million and the PCAST recommendation of $250 million. Among the several agencies included in the ICEI, only the DOE received any support, consisting of $7 million for the ICEI component of NERI and $1.5 million for fossil-energy activities.

Although this initial effort at bolstering US engagement in international cooperation on ERD^3 resulted in little new funding, it appears to have started an important educational process within the federal agencies and Congress on the importance of the international dimensions of energy issues and the opportunities these present for the United States. Within federal agencies, international issues have often been accorded "second class" status out of concern that funding on international cooperation either would divert resources from core domestic RD^3 activities or would be targeted by Congress for cuts, or both. The PCAST-99 report and the ICEI provided a foundation and framework for arguing for these activities on their merits, and private communications to us from agency staffers have indicated that the result has been a degree of senior-management interest in prospective international-cooperation programs that is unprecedented.

In Congress, growing awareness of the importance of these issues was reflected by the Byrd language in the FY 2001 Energy and Water Appropriations Senate Conference Report, which although it provided no new funds for international activities did endorse much of the approach recommended in PCAST-99 and embodied in the ICEI (58):

> The Committee supports efforts to increase international market opportunities for the export and deployment of advanced clean energy technologies—end-use efficiency, fossil, renewable, and nuclear energy technologies. The Administration should improve the Federal Government's role in the national and

> international development, demonstration, and deployment of advanced clean energy technologies by establishing an interagency working group jointly chaired by the Departments of Energy and Commerce and the US Agency for International Development. This working group should also include representation from the Departments of State and Treasury, Environmental Protection Agency, Export-Import Bank, Overseas Private Investment Corporation, Trade and Development Agency, and other departments and agencies, as appropriate. The Administration should also consult with the private sector and other interest groups on the export and deployment of clean energy technologies through the establishment of an advisory panel. Progress on the international deployment of clean energy technologies should be reported annually to Congress by March 1. The Administration should analyze technology, policy, and market opportunities for further international clean energy program development and provide Congress a 5-year strategic plan by June 1, 2001. This plan should be developed in consultation with the advisory panel.

In the broader energy community, the PCAST-99 report has been widely disseminated and well received. Its findings have been presented to good reviews in briefings and symposia around the world (including, for example, in the Joint Sino-US Science and Technology Forum cosponsored by the Chinese Ministry of Science and Technology and the White House Office of Science and Technology Policy, and in bilateral US-Indian discussions organized under the auspices of the academies of science and engineering of both countries) and have been cited favorably in subsequent major studies of international energy issues (59) and energy-cooperation possibilities (60).

Although the study's tangible achievements as measured by new funded initiatives have been meager, it is still early in this effort, and it may be hoped that the thinking and discussion that PCAST-99 has helped to stimulate will bring more substantial results in the future.

CONCLUSIONS

The United States and the world face an array of energy-related challenges in the new century, among them providing affordable and reliable supplies of energy adequate to maintain and expand prosperity where it already exists and to create it where it does not; limiting overdependence on imported oil; reducing the impacts of energy supply on air and water quality locally and regionally; minimizing the contributions of nuclear energy to nuclear-weapons dangers; and reducing the risks from greenhouse gas–induced global climate change. Developing and deploying greatly improved energy technologies, in the United States and abroad, is not the whole solution to these challenges, but it is an indispensable part of the solution.

No technological "silver bullet" is in sight or likely to emerge—no single approach that can do most or all of the job—nor is there any major class of technological options that the world can currently be confident that it can do without. Efforts must be made to maximize the capabilities and minimize the liabilities of all the options with significant potential to contribute to the world's needs: improvements in the energy efficiency of vehicles, buildings, and industries; renewable-energy sources; advanced fossil-fuel and nuclear-fission technologies; and nuclear fusion.

Although the private sector will play an increasingly dominant role in the evolution of the world's energy systems, the public interest in energy-technology innovation exceeds the private interest in it because of the immensely important public-goods and externality issues that are entangled with energy, as highlighted in the list of challenges enumerated here. This is the rationale for the engagement of government in these matters, in partnership and symbiosis with the private sector. But the extent and quality of the engagement of the US government with energy research, development, demonstration, and deployment today—and in international cooperation related to this—is not commensurate with a realistic appraisal of the challenges, the opportunities, and the current and future roles of the private sector.

Public pressure and political will to strengthen the government's efforts in this domain have been feeble for many reasons, including (until very recently) many years of low energy prices, no gasoline lines, no electricity-supply crises, and an accompanying lack of interest in long-term threats arising from the linkages between energy and the economic, environmental, and national-security dimensions of human well-being. But another contributing factor has been the disarray and dissension in the community of energy specialists more or less knowledgeable about these matters, who have mostly preferred to promote their own favorite energy-technology solutions and disparage the others, rather than speaking with one voice in favor of a responsible portfolio approach to improving the entire menu of energy technologies available.

The three PCAST energy studies discussed here constitute, we think, an "existence proof" that a consensus approach to federal strategy for ERD[3] and international cooperation with respect to it is possible, is desirable, and can lead to something more than lowest-common-denominator results. All three of the panels that produced these studies were diverse in their composition—representing a range of disciplines, expertises, energy and nonenergy backgrounds, and public/private/academic/NGO-sector orientations—and all were able, despite this diversity and the traditionally contentious character of debates about energy, to reach unanimous conclusions and recommendations. They were also able to present and promote their results in a way, we believe, that underlines what ought to be the inherently bipartisan character of a sensible energy-technology strategy: The economic, environmental, and security interests and values at stake in the energy arena are equally prized, and the complementary roles of the private and public sector equally respected, in both of the major US political parties.

Although the degree of implementation of the PCAST energy recommendations has been modest, it may be hoped that the content of these reports and the nature of the process that produced them can serve as a basis and an example for continuing and widening efforts to construct the coherent national and global energy-innovation strategy that the challenges so urgently require.

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