CHAPTER 7
CROSSCUTTING ISSUES AND SYNTHESIS

DOE is not presently constituted so as to perceive its energy R&D program as constituting a portfolio of investments, each intended to achieve specific objectives related to overall criteria and policy goals. The portfolio approach would have R&D managed as a whole, with an emphasis on overall performance.

SEAB Task Force on Strategic Energy Research and Development[1]

This chapter synthesizes and extends the Panel's analysis of Federal energy R&D with four emphases: (1) an assessment of DOE's applied energy-technology R&D portfolio as a whole; (2) linkages between R&D and demonstration and commercialization; (3) international issues; and (4) R&D management.

PORTFOLIO ASSESSMENT

Among the criteria that can be applied to judge the appropriateness and effectiveness of DOE's energy R&D portfolio are the following.[2]

- Strategic criteria. The overall portfolio should address effectively the principal energy-related economic, environmental, and security challenges facing the nation, and should strengthen U.S. science and technology leadership.

- Diversity criteria. The portfolio should include a diversified set of R&D projects with a balance across technologies, time frames, and degrees of technical risk. Such diversity hedges against major failures and changing assumptions and external conditions, including a range of environmental scenarios.

- Public-private interface criteria. Projects in the Federal portfolio should have potential payoffs to society as a whole that justify bigger R&D investments than industry would be likely to make on the basis of expected private returns. The projects should be shaped, wherever possible, to enable relatively modest government investments to effectively

[1] SEAB (1995b).
[2] A similar set of criteria was presented in the Secretary of Energy Advisory Board's 1995 study of strategic energy R&D, SEAB (1995b).

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.

- Other project criteria. The projects within the portfolio, besides meeting or helping to meet the preceding three criteria, should have strong technical merit, well defined goals as a function of time and effort; and components that are appropriately funded, structured, and managed so as to maximize the chance of meeting those goals. The projects should also be structured, insofar as possible, to complement and reinforce other projects across the portfolio.

Chapters 3 through 6 treated the major energy technology programs in DOE's R&D portfolio—what exists in these programs now and proposed changes to what exists—with emphasis on the "public-private interface criteria" and the "other project criteria" mentioned above. In what follows here, the existing and proposed DOE programs are discussed in terms of those criteria that relate to the portfolio as a whole or to the interactions among its parts.

Strategic Criteria

The key issue in relation to the strategic criteria is the prospective leverage of the R&D portfolio as a whole in addressing the principal energy-related economic, environmental, and national-security challenges.

Leverage Against Economic Challenges

On the energy-supply side, R&D and economies of learning in production are expected to dramatically reduce the costs of a range of emerging energy technologies to broadly competitive levels. Factors that contribute to the prospects for such cost reductions for a technology include: demonstrated performance in the laboratory; multiple technology pathways to increase the likelihood of achieving cost and performance goals; relatively small scale, modular, standardized designs to minimize field construction and to allow steep learning curves (e.g., rapid cost reductions) in mass production; inherent cleanliness and safety to minimize regulatory controls and the cost of waste and emissions capture and disposal; and inherently low materials intensity to keep intrinsic costs down.

Costs for both energy-supply technologies and efficient-end-use technologies are decreasing in many cases, and the budgets recommended by the Panel will accelerate and strengthen these cost reductions and performance improvements. For example, advanced integrated gasification combined cycles (AIGCC) for use with coal or biomass can probably achieve electricity generation costs in the $0.04/kWh to $0.06/kWh range, depending on fuel costs. High-temperature solid-oxide fuel cells and gas turbine bottoming cycles can probably reach even lower generation costs, perhaps $0.03/kWh by 2010. Wind-generated electricity is expected to continue its sharp cost reductions. For Class 4 winds without energy storage, costs are projected to be in the $0.03/kWh to $0.035/kWh range by the year 2005, for investor-owned utility and independent-generating company financing respectively, and $0.025/kWh to $0.03/kWh by 2020 (Chapter 6).[3] For U.S. average solar insolation, PV-generated electricity is projected to be in the $0.07/kWh to $0.11/kWh in the 2010 time frame, for home mortgage or independent generating company

[3] Investor-owned utility financing terms are assumed to be 11.7 percent real; independent generating company financing terms are assumed to be 13 percent real.

financing respectively, and \$0.045/kWh to \$0.075/kWh by 2020.[4] On the other hand, today's natural gas combined-cycle (NGCC) systems produce power at a cost of around \$0.03/kWh; no other electricity generating technology can compete today with NGCC's cost.

This simplified portrayal of electricity generation costs now and in the future leaves out some important considerations, such as the following:

- Resource availability. Even though natural gas combined-cycle systems are highly competitive in many parts of the United States, low-cost gas is not available everywhere. There are markets—particularly international markets—where coal, nuclear, wind, biomass, or solar thermal technologies could be the least costly option.

- Value. Simple cost comparisons do not consider the value of the energy, which depends on where it is generated and used. For example, electricity generated at a building with a fuel cell, PV module, microturbine, or other distributed generation technology avoids losses in the electricity transmission and distribution system, can reduce overloading in the distribution transformers, and can provide other benefits[5] that central-station power production cannot. Such "distributed utility" applications offer an important market opportunity for these technologies.

- Market strategies. This comparison does not take into account strategies—such as the production of multiple products or the generation of multiple benefits—for providing energy at competitive costs. For example, biomass can be used to generate electricity, heat, fuels for transport, and chemicals at the same time (Chapter 6). Produced in concert, these can be highly market-competitive products, whereas if they were produced individually they would not be as competitive.

The projected costs for the technologies described above and in Chapters 3 through 6 have an important implication. In the near- to mid-term, NGCC systems are likely to be the lowest cost supply wherever low-cost[6] natural gas is available. NGCCs also have the advantages of relatively quick installation (less than 2 years) and moderate scale (less than 200 megawatts). Consequently, sales of other technologies will be limited in the United States and in other regions where low-cost natural gas is available for electricity generation, for as long as that availability lasts.[7] For the United States to maintain scientific and technological leadership in these other energy supply technologies—coal, nuclear, renewables—it will be essential to broaden both the R&D and the demonstration and commercialization focus to include international opportunities, which are expected to be very large (see below). If U.S. manufacturers fail to establish a strong presence in these international markets, they will lose potential revenues that will be captured by their foreign counterparts. In turn, lower revenues may translate into lower R&D investments, which could end up reducing their competitiveness still further.

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[4]Home mortgage financing is assumed to be 6.5 percent real, plus 0.5 percent insurance, with a 30-year term.
[5] This might include using some technologies to cogenerate heat for use in the building.
[6] Low-cost refers here to the highly competitive cost of natural gas; it is not intended to suggest that natural gas is priced below its long-run commodity price level.
[7] Geothermal may compete in some areas, but hydrothermal resources on which it now depends are limited; wind may be more broadly competitive if an aggressive wind-commercialization program is launched.

Leverage Against Environmental Challenges

Although energy purchases account for about 8 percent of U.S. GDP, energy technologies generate far larger shares of many of the most troublesome "conventional pollutants"—oxides of sulfur and nitrogen, hydrocarbons, carbon monoxide, particulate matter—as well as of the GHG carbon dioxide. Improved energy technologies can substantially reduce the emissions of all of these pollutants. We emphasize carbon dioxide ("carbon") emissions here, because they are so challenging to control (Chapter 1) and because controlling them also controls many of the other environmental burdens.

Figure 7.1 illustrates, in a highly stylized and schematic way, how the factors most germane to the analysis of the leverage of new energy technologies against CO_2 emissions can be portrayed in a single diagram: the length of time until a new technology is ready to begin penetrating the market, the cost of the R&D effort needed to get to that point, and the rate at which the technology could penetrate the market (reflected in the diagram as the rate of increase in avoided CO_2 emissions) after that time.[8] With some modifications, such a diagram could also show the effect, on the potential for emissions avoidance, of the different sizes of the various energy-supply or end-use markets being penetrated.

In the time available for this study, the Panel has not been able to complete the sorts of analyses that would be necessary to specify the relevant market-entry points, associated research investments, and plausible penetration rates—and the uncertainty ranges associated with all of these—with any confidence. Figure 7.1 is based on very approximate understandings of needed research investments and market-entry points developed in the course of this study, and on crude guesses about penetration rates (which were assumed to be uniform across the technologies shown, in the absence of the sort of analysis that would be required to do this in a differentiated way).

To avoid excessive clutter in this purely illustrative figure, moreover, it omits many other technologies with significant long-term potential to reduce carbon emissions, including biomass, photovoltaic, and solar-thermal technologies, as well as long-term end-use-efficiency technologies other than PNGV and residential buildings. Nor does it include a number of options that could have a substantial impact before 2010, based largely on R&D that has already been done. The potential of these earlier-impacting options has been separately examined by DOE in a recently released report.[9]

Figure 7.1 is not, therefore, an actual picture of the carbon displacing potential of the energy R&D portfolio that the Panel is proposing, or of the combined potential of the fruits of past as well as future R&D. It is, rather, a highly preliminary, partial, and schematic depiction of potential leverage that (1) illustrates what we believe DOE should be doing in the way of portfolio analysis, with a much larger analytical effort behind it than they or we have mustered until now, and (2) shows timing and magnitudes of conceivably avoided carbon emissions roughly consistent with what other major recent studies of the potential of new technologies for this purpose have found.

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[8] Figure 7.1 differs from the very similar Figure ES.2 in the Executive Summary only in having substituted, for the latter's narrow wedge portraying the potential contributions of Advanced Integrated Gasification Combined Cycle coal technology, a wider wedge that includes not only AIGCC but also advanced fuel-cell and carbon-sequestration technologies that could help alleviate the carbon constraint on fossil-fueled power generation.

[9] DOE (1997).

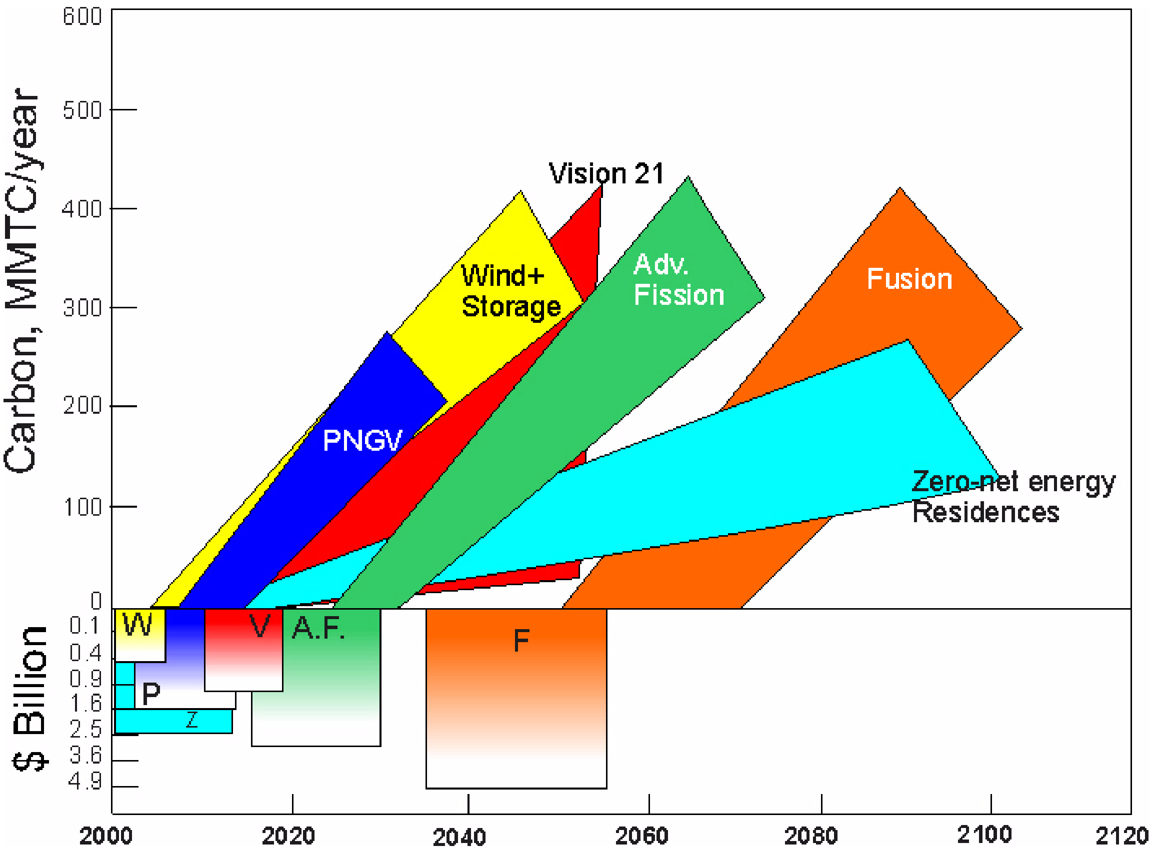

Figure 7.1: Schematic diagram of leverage of energy R&D against carbon emissions. The diagram shows the approximate range of times when a technology might be available for commercial use—identified as where the shaded wedges touch the time-axis; the potential carbon savings as the technology penetrates the market—depicted by the shaded wedges indicating a range of penetration rates; and the approximate cost of the R&D to develop these technologies to commercialization—depicted by the squares at the bottom of the drawing, which have areas proportional to the discounted present value of the R&D costs. This does not include the cost of commercialization. The width of the wedges and shading in the boxes depict uncertainty in these estimates. Maximum slopes of penetration-rate wedges are based on 100 percent capture of the market for new units and specified turnover times for old units: 15 years for cars, 40 years for electric-power plants, 80 years for residential buildings. For simplicity, carbon intensities for the various sectors are assumed to be frozen at 1995 levels. Funding estimates are for applied technology development only, they do not include fundamental science research. Funding for buildings includes commercial buildings, for which carbon savings are not shown. The Vision-21 scenario assumes widely applicable, low-cost, and geologically secure carbon sequestration which allows fossil power to be decoupled from carbon constraints, as in the case of nuclear and renewable energy. Large, long-term R&D programs assume international collaborations. With refinement and more nuanced analysis behind it, such an approach to illustrating the leverage of an R&D portfolio versus time and investment could be very informative. To keep the figure and the analysis as simple and transparent as possible, carbon emissions were assumed to be frozen at 1995 levels of residential, 270 million metric tonnes of carbon/year (MMTC/y); commercial, 220 MMTC/y; industrial, 460 MMTC/y; transport, 460 MMTC/y; and other; for a total of 1440 MMTC/y (EIA, 1996b). The utility sector generated 480 MMTC/y in 1995, accounted for in the residential, commercial, and industrial sectors. In addition to the 15 years for turnover of the average vehicle, 5 years was added to provide time to develop the production infrastructure. Emissions within each sector are charged against the highest emissions component of that sector. The potential contribution of each technology is considered independently of all the others. This is a highly simplistic and stylized comparison that ignores variations in carbon emissions within sectors over time. It also ignores overall growth in carbon emissions over time, assuming that increased energy use in the economy will be offset by decreased carbon intensity. Finally, it considers the ultimate market for each technology independently, not accounting for competition between technologies, leading to high estimates of the potential contribution from particular technologies. Future R&D costs for all the technologies are in FY1997 dollars and are discounted to the present at a constant 3 percent discount rate to provide a net present value.

Most of the advanced energy technologies currently under development by DOE reduce or eliminate carbon emissions or address other environmental problems. Advanced fossil technologies substantially reduce carbon emissions, but not to the level needed to stabilize atmospheric carbon at reasonable levels unless sequestration is successfully developed and used (see Figure 7.2). Nuclear and renewable energy generally emit little net carbon, and, of course, energy-efficiency measures generate little net carbon and can significantly reduce fossil fuel use.[10]

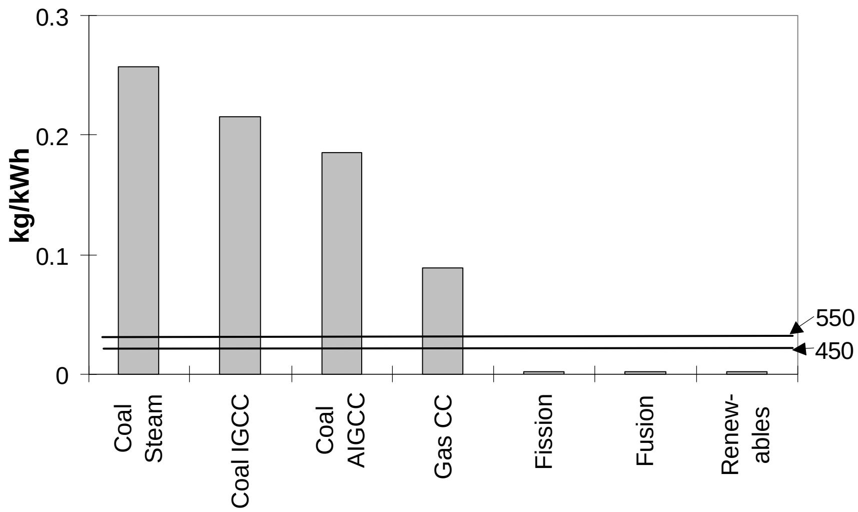

Figure 7.2: Carbon emissions for various electricity generation options. Emissions estimates are based on heat rates of 10000, 8350, 7200, and 6200 Btu/kWh for coal steam, IGCC, AIGCC, and Gas CC plants, respectively, and carbon contents of 24.4 and 13.6 kg per gigajoule for coal and gas, respectively. The horizontal lines roughly indicate the average global emissions level in the year 2100 per kWh to keep atmospheric carbon levels at two times preindustrial levels (550 parts per million by volume, ppmv) and 1.6 times preindustrial levels (450 ppmv). Sequestration will be required or a substantial fraction of electricity will have to come from nuclear and renewable energy to reach these average per kWh emissions levels. Estimated year 2100 carbon emissions for 550 ppmv assume a carbon trajectory rising from 6 PgC/yr global emissions today, to 10 PgC/yr in 2035, and then falling to about 6 PgC/yr in 2100 and continuing to fall thereafter. If world per capita electricity consumption in 2100 is 6.3 times 1990 levels of a net 10,400 billion kWh, or 65 billion kWh, as depicted in the IPCC IS92a reference scenario, and if electricity accounts for one-third of carbon emissions across the entire global economy, then 2 PgC divided by 65 billion kWh gives an average emission level of .031 kg carbon per kWh. At 450 ppmv, the result is 0.021 kg carbon per kWh. Carbon trajectories are drawn from Edmonds et al. (1996).

Where and when these technologies are used is also important. Advanced fossil technologies by themselves can provide large carbon emissions reductions in the near- to mid-term, particularly in countries such as China and India, which are rapidly increasing their energy use, primarily through inefficient coal power. Given the projected low cost of natural gas in the United States, such international opportunities will be the most important markets for advanced coal technologies over the next decade or two. If sequestration proves to be secure, cost-effective, and widely applicable, then advanced fossil power-

[10] Nuclear and renewables emit some net carbon because of the production of cement, for example, or other materials in their construction; efficiency may emit some carbon if additional materials are required, but amounts are generally very small.

sequestration systems might be an important component of a longer term strategy in a carbon-constrained world.

Leverage Against Security Challenges

Among the energy-related security challenges described in Chapter 1—including the ramifications of excessive dependence on insecure supplies of foreign oil, nuclear proliferation, and instabilities in the developing world arising from energy-related economic or environmental problems—the discussion that follows here will treat only the oil- import challenge.

A variety of technologies can contribute to diversifying supplies and reducing oil-import dependence – closing the oil import gap, as illustrated by the highly approximate calculation depicted in Figure 7.3. On the fuel supply side, the technologies illustrated in Figure 7.3 include increasing domestic oil production above "business-as-usual" (Chapter 4) and ethanol from biomass (Chapter 6). Increasing supplies both in the United States and abroad would help control oil prices and the risk of an oil shock. Of course, if world oil market prices rise, so will the price of such domestic supplies. This would not reduce an oil shock much, but it would reduce the transfer of wealth abroad, keeping the currency directly in the U.S. economy. On the demand side, advanced car (PNGV), light-truck, and heavy-truck technologies (Chapter 3) can have a substantial impact as well. With rapid commercialization, all of these supply and demand technologies together can substantially close the import gap. There is no silver bullet, but a broad range of responses can make a major difference. Instead of importing nearly 16 million barrels of oil per day in 2030 at a cost of $120 billion (assuming $20 dollars per barrel), these technologies could reduce imports to something on the order of 6 million barrels per day of oil under this highly aggressive scenario.

Additional technologies could further narrow this import gap. Opportunities include, for example, compressed natural gas and natural gas-to-liquids technology (Chapter 4); the production of industrial chemicals from biomass rather than petroleum; further improvements in transport technologies; and, in the long-term, hydrogen from fossil fuels, biomass, or other sources (Chapters 4 and 6). Given the long period of time needed to do the research, commercialize the technology, and significantly penetrate the market, several decades of concerted effort will be required to substantially close the oil-import gap that the United States currently faces.

How much is the United States spending to address the oil security problem? For the technologies shown in Figure 7.3, the Federal government is currently spending — roughly — $175 million on advanced transportation technologies, $25 million on fuels from biomass resources such as agricultural wastes, and almost $50 million to improve recovery from marginal oil and gas fields.[11] (There is, in addition, R&D on hydrogen and other technologies that can also help reduce oil imports in the longer term.) This $0.25 billion spent on R&D can be compared to the roughly $120 billion the United States currently spends annually on oil, of which about half is imported. This is equivalent to an R&D expenditure of about $0.04 per barrel of oil used by the United States or about $0.001 per gallon. Changes in expenditures on oil due to normal market fluctuations in the price of oil just in the past year have been 100 times greater[12] than the investment we are making in R&D.

[11] There are other investments as well, such as in hydrogen, electricity—if electric-powered vehicles are someday significant, natural gas—if compressed natural gas vehicles become significant; and energy efficiency in buildings and industry—where oil is backed out; etc. Only the near- to mid-term transport sector is examined here.

[12] Oil prices varied from about $17.25 in January of 1996 to $22.50 in December of 1996 back to about $17.50 in April 1997. EIA (1997b).

The calculations depicted in Figure 7.3 assume rapid commercialization, which is often difficult to achieve in practice. Production of alternative fuels, for example, poses substantial risks for developers who could easily be forced out of business by price-drops engineered by the OPEC cartel; conversely, there could be more short-term cartel-driven price hikes. Consumers have little interest in fuel-efficient vehicles when fuel is a small part of the cost of owning and operating a car and the more efficient vehicle may have higher initial capital costs even if overall life-cycle costs are the same as those for today's conventional vehicles.

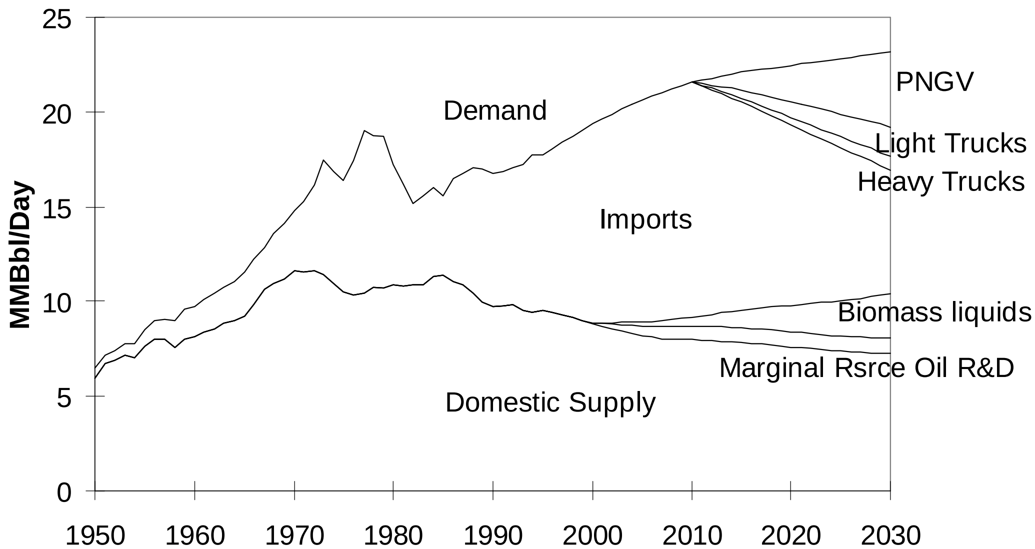

Figure 7.3: Narrowing the oil import gap. This chart shows data for 1950 to 1995, EIA projections for 1995 to 2015, and then extends the EIA 2005 to 2015 trends as straight line projections to 2030. The EIA projection to 2015 include improvements in new car mileage reaching 32.6 mpg, from the 1995 level of 27.5 mpg, and in new light truck mileage reaching 24.2 mpg, from the 1995 level of 20.6 mpg. The vehicle efficiency improvements depicted in the figure assume that R&D is completed by 2004 and that commercial production is under way by 2010, with straight line penetration to 100 percent of the market by 2030. Improvements are for cars (40 percent of the transport fuel demand), to 80 mpg, or a 60 percent reduction in fuel use; light trucks (20 percent of transport fuel demand), a 60 percent reduction in fuel use; heavy trucks (15 percent of transport fuel demand), a 40 percent reduction in fuel use. The incremental supply of oil due to R&D on marginal resources is based on the DOE Oil and Gas program estimate as incorporated in the EIA projections (EIA 1997a). Biomass-liquids estimate is based on an aggressive program to produce ethanol from cellulosic-biomass. Many other technological possibilities are not shown, including gas-to-liquids and compressed natural gas technologies; advanced aircraft; the substitution of biomass feedstocks for petroleum, and many others. This simple scenario does not consider complementary policies that will likely be needed to achieve such rapid market penetration.

Diversity Criteria

Diversity criteria include the balance of the R&D across technology pathways, time frames, and degrees of technical risk. Figures 7.1 and 7.3 provide schematic illustrations of the power of portfolio diversity in addressing major energy-related challenges over a range of time frames.[13] The portrayals in those figures do not fully account, however, for technical and commercialization risks (including risks of public acceptance), although the range of entry points and variation of slopes portrayed by the truncated wedges in Figure 7.1 embody some of this.

In general, the further in the future that the technology is likely to become available, the higher the risk that it might not be successfully developed within the projected time frame, cost, and performance level. But this does not mean that these longer-term, higher-risk possibilities should not be in the portfolio. Notwithstanding the need for significant emphasis on the probability of success offered by the elements of the portfolio, some high-risk elements are essential if the portfolio is to provide adequately for innovation in the long run.

Technologies requiring long-term development—e.g., technologies that require extensive fundamental science and engineering work before they can be brought to the point of commercialization—not only have high technical risks but also, often, high potential returns. Also, the research is often relatively inexpensive in its early stages. Of course, as the technology moves toward engineering development the costs generally increase, sometimes greatly, but this is accompanied by declining risk and increasing proximity of returns.

The balance between fundamental science and engineering on the one hand, and applied technology development on the other is a useful characterization of the overall time frame and risk of a portfolio. However, it is also important to recognize that the higher cost of applied technology development requires greater resources than fundamental science and engineering. Figure 7.4 makes this comparison for the current DOE energy technology portfolios; Table ES.2 provides greater detail.

As can be seen in Figure 7.4, 57 percent of the FY1997 R&D budget is for fundamental research. The Panel was not able to review in detail the Basic Energy Sciences or other energy-linked Energy Research budget lines, other than the fusion program. Consequently, the Panel makes no recommendations about the future sizes of these budgets. However, because advances produced by research in the Basic Energy Sciences category provide an important part of the expanding knowledge base on which progress in applied energy-technology R&D in the public and private sectors alike depends, DOE may want to consider expanding its support for Basic Energy Sciences as the applied energy-technology R&D areas grow.

Project-Level Criteria

Most of the Panel's evaluation of existing and proposed ingredients of DOE's applied energy technology R&D portfolio in terms of the public/private interface criteria and other project-level criteria mentioned in the "portfolio criteria" list at the beginning of this chapter has already been presented in

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[13] Note that programs such as PNGV, Zero-Net Energy Residential Buildings (ZNERB), and even PVs include a broad collection of technologies, including, for example: PNGV—advanced hybrid engine or fuel cell-battery-electronic drive train systems, aerodynamic styling, lightweight materials; ZNERB—advanced passive solar architectural design, high-performance insulants and windows, building integrated renewable energy equipment, ground-source heat pumps, and advanced appliances; PV—multiple PV material pathways, advanced power electronics. These programs themselves represent portfolios with a range of timing, risk, and return among the technology elements. For a technology group such as PV, it is useful to think of it as a technology stream with a series of increasingly high-performance and low-cost outputs.

Chapters 3 through 6. Here we add just a few points on public-private partnerships and on linkages between projects.

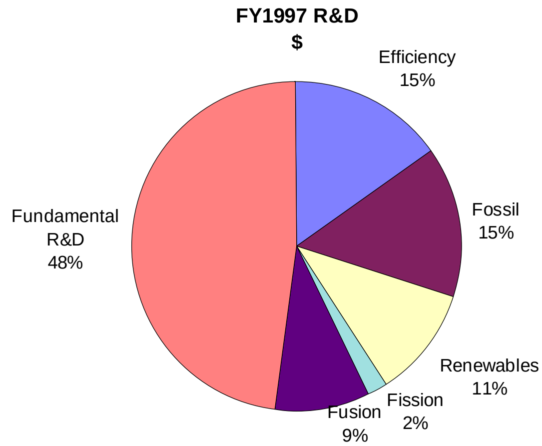

Figure 7.4: Fundamental and applied energy R&D in the FY 1997 budget. Specific energy R&D activities are listed for the FY 1997 budget. The values are also listed in Tables ES.1 and ES.2. The total shown includes the $1282 million of the applied energy technology programs of Table ES.1 and the $1180 million of the "Energy Research" category of Table ES.2; the $393 million in the "Other" categories of Table ES.2 are not included here. Most of the Fusion budget is for fundamental science and engineering; including this in the Fundamental R&D category—as is done within the official congressional budget and programmatically—brings the fundamental R&D budget to about 57 percent of the total shown here.

Partnerships

The Panel found numerous examples of well-functioning partnerships between industry, national laboratories, and universities. (See Chapters 3 through 6.)[14] Such partnerships should be encouraged throughout Federal energy R&D programs because the communication and coordination they entail improve the efficiency and effectiveness of the public and private R&D programs alike, because they increase the market relevance of Federal R&D and facilitate technology transfer, and because they leverage Federal dollars with private ones. The current level of industry cost-sharing with DOE is estimated to total more than $300 million per year.[15]

The importance of private-sector/public-sector partnerships was highlighted by the SEAB Strategic Energy R&D study:

> *The Task Force recognizes the concern expressed by some that cost-sharing may constitute a form of "corporate welfare". However, we observe that cost-sharing was introduced by the Reagan and Bush Administrations in the 1980's to spur R&D productivity and to achieve three objectives: leverage government R&D spending; introduce market relevance into R&D decisionmaking; and accelerate the R&D process and the transfer of results into the economy and the marketplace. The reductions and*

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[14] OIT (1997).

[15] Based on responses by DOE to a questionnaire developed by the Panel. It does not include all programs and is a conservative estimate.

foreshortening in corporate R&D programs strengthen the need for cost-sharing ……… With private-sector budgets cut and refocused toward near-term results, cost-sharing enables companies to explore R&D options that otherwise would be screened out, and to do so with a longer time horizon.[16]

Linkages

A number of opportunities for linkage and synergy across projects in different sections of DOE's applied energy technology R&D effort were identified in Chapters 3 through 6. These include, to name a few:

- Integrated gasification technologies to produce (1) electricity from biomass and coal separately or in cofiring applications, and (2) fuels such as hydrogen or methanol from biomass or coal.
- Fuel cell technologies for use with biomass, coal, hydrogen, or natural gas in the buildings, industry, transport, and utility sectors, particularly in a cogeneration mode.
- Gas turbine technology for use with biomass, coal, natural gas, and high-temperature solar thermal systems—ranging in size down to microturbines—for use in the buildings, industry, and utility sectors.
- Drilling and excavation technology, for use in geothermal energy, oil and gas development, and urban infrastructure.
- Power electronics, for use in high-efficiency electric motor drive systems for industry, electronic drive trains for vehicles, PV DC to AC inverters, variable speed wind turbines, and utility grid power conditioning.

Similarly, there are numerous important linkages between the work done with the DOE Office of Energy Research Program, including Basic Energy Sciences, and the applied technology programs.[17] In addition to items mentioned above, these linkages include:

- Biological processes—for production of fuels from biomass and the production of dedicated energy crops.
- Catalysis—for producing designer molecules from feedstocks, such as biomass or coal to fuels, or natural gas to liquids.
- Combustion processes—for combustion of biomass, coal, gas, oil, etc., and minimization of air toxics.
- Electrochemistry—for fuel cells, batteries (advanced electrolytes).
- Geophysics—for oil and gas exploration and production, and for producing geothermal energy..

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[16] SEAB (1995b, p. 47).

[17] The Panel did not examine the R&D portfolio of DOE's Office of Energy Research (including Basic Energy Sciences) in depth, as it did for the applied energy technology R&D programs.

- Materials—for high temperatures with gas turbines, fuel cells, solar thermal receivers, and others; for fatigue resistance—especially wind turbine blades; for power electronics; for photovoltaic conversion; for high-temperature superconductors; for durable ceramics; for hydrogen storage; and for resistance to materials damage by radiation.

- Separations Science—for separating wastes, including nuclear, or concentrating products

These numerous technical linkages between offices and programs are not consistently dealt with by DOE; better coordination is required. This subject is discussed in more detail below under "Management".

Concluding Observations on Portfolio Assessment

As detailed in Chapters 3 to 6, the Panel has proposed a variety of changes—reductions, redirections, and increases—in the array of applied-energy technology R&D activities supported by DOE. We believe that the recommended changes would substantially improve the country's energy R&D portfolio in relation to the criteria that have been presented here, including above all the balance and robustness of the portfolio in positioning the country to address the energy-related economic, environmental, and national security challenges of the century ahead.

The Panel shares with the authors of the Secretary of Energy Advisory Board review of Strategic Energy R&D two years ago the conviction that DOE, as it manages the evolution of this R&D effort in the future, needs to devote expanded and continuing effort to portfolio-wide assessment of the sort that the SEAB Strategic Energy R&D study described and that the Panel has attempted to further develop and apply.[18] In the process of modifying and managing the portfolio over time, moreover, industry participation (for the reasons described above) and external peer review (discussed further below) will both be essential.

The ongoing, iterative process of portfolio development and assessment should include setting goals for all of the technologies in the portfolio and systematic monitoring of progress toward those goals, with the help of external reviewers. The goals should be specific, quantified (with progress milestones and cost objectives), realistic, and clearly related to the major energy-related challenges the country faces. Along with short-term monitoring of progress toward these goals, moreover, the portfolio assessment effort should include longer-term evaluation of the track records of DOE's R&D programs, including successes, failures, and lessons learned. (Box 7.1 elaborates on the concept of track records. Box 7.2 illustrates the lessons-learned idea by summarizing some of the lessons this Panel took away from its own review of the recent history of U.S. energy R&D.)

In addition, better coordination is needed for the crosscutting elements of the portfolio. This includes better coordination of technology R&D such as fuel cells, power electronics, gasification, hydrogen, and others that cut across the applied technology programs. Better coordination is also needed to meet national challenges, particularly in response to carbon emissions and oil security. These issues are examined later in this chapter.

[18] SEAB (1995b).

Box 7.1: The Importance of Track Records

Establishing a track record of past performance matters. A consistent, transparent, and credible procedure for establishing the benefits and costs of past R&D can establish a common basis for understanding what has been achieved and build consensus on what should be done. A variety of methods can be used to document track records, including the following:

- An aggregate portfolio approach: Establish a systematic procedure for quantifying the benefits versus costs for all DOE energy R&D technologies that have gone to market. Establish clear, peer-reviewed procedures for collecting the data used to estimate the benefits and costs.

- A case-study approach: Establish a systematic procedure for documenting the reasons why a program succeeded or failed and the lessons learned. Generate a checklist of things to do and things to avoid.

A good example of how to assess past performance is the tracking done by DOE's Office of Industrial Programs (OIT) for technologies developed through cost-shared R&D projects with industry. For technologies that have reached the marketplace, data on sales, energy saved, environmental benefits, and marketing issues and barriers are collected each year from technology manufacturers and end-users. Using these data, it is then possible to compute for each year the net economic benefit from OIT-supported R&D programs. OIT also collects information on how and why technologies failed.

Box 7.2: Lessons Learned From the Recent History of U.S. Energy R&D

The case studies and other information reviewed by the Panel provide lessons that can guide energy R&D project selection, funding, and management:

- Government/industry/national-laboratory/university R&D partnerships can be effective mechanisms for the development and application of technology with potentially large returns to the nation.

- Equitable and stable cost sharing is essential for the project partners to commit to the project's full term.

- Clear technical, performance, cost, and schedule goals must be stated and agreed upon before formal obligation of significant project funds, along with sound criteria for changing or canceling the project if reasonable progress toward those goals is not met. An oversight process should be established to provide periodic independent evaluation of project management, performance, schedule, cost control, and risks. Results should be carefully documented to establish a track record of what worked and build consensus on what to do next.

- Federal support of demonstration and commercialization activities should be temporary, efficient in driving down costs, minimize administrative overheads, and provide clear progress toward making the technology commercially competitive. Wherever possible, funding should be dominated by the potential industrial beneficiaries of the demonstrated technology.

- Although federally funded projects cannot be insulated against political interference and second-guessing, the government should resist making politically determined decisions.

- The government should support those energy R&D projects that can lead to U.S. industries gaining an early entrants advantage in international markets, especially when significant global environmental benefits can be achieved.

COMMERCIALIZATION ISSUES

Research and development are part of a process intended to lead to the successful commercialization of innovative products in the marketplace. Traditionally, this process was viewed as orderly and sequential—like a pipeline with researchers injecting basic science at the first station, and then subsequently and independently injecting applied research, development, and demonstration, until commercial products finally emerged. There was believed to be little interaction among these various stages.

This model worked passably well for many years (although it often failed to reflect actual practice). With globalization and increased competition, ever shorter product cycles, and increasingly sophisticated technology, this model no longer works well and can even be seriously counterproductive. Rather than a pipeline, a more realistic image today might be a complex tapestry, with the various stages—basic science, applied research, development, demonstration, commercialization—all strongly entangled and inseparable throughout the process. R&D today is a dynamic process with extensive interactions among all stages. This is now widely observed and understood and is a key factor in the conduct of most corporate research. The SEAB Strategic Energy R&D study also made this observation and recommended that DOE management practices take this into account.[19]

This interconnectedness has several important implications: First, fundamental scientific research should be better coordinated with applied R&D programs. Specifically, some of the overall fundamental research effort should be directed to addressing scientific questions identified in the applied R&D programs, to enhance the prospects for accelerated technological progress in these programs. While differently motivated from basic research conducted without thought of practical ends, as has been the case for much federally supported basic science since World War II, the research needed to support the technology programs is nevertheless fundamental research, not applied research (see Box 7.3). This issue will be revisited in the Management discussion below.

Second, applied research and development, in turn, should be carried out and should, in most cases, be driven by consideration of markets (through demonstration and commercialization). For this to happen requires the formation of industry led partnerships with national laboratories and universities. This is increasingly being done and the trend should be strengthened as discussed above.

Applied R&D is not truly successful unless the technologies developed are successfully commercialized. New technologies and embryonic industries face particular difficulties. In many cases, new technologies face the chicken-and-egg problem of being generally high cost and thus limited to low market volumes, but needing large market volumes to drive costs down; and embryonic industries don't have the resources to provide the necessary support.

As a result, specific commercialization efforts may be appropriate to address the barriers facing particular technologies. The overall process can be represented as finding ways to climb over "the mountain of death", represented by the high costs of first-of-a-kind products, or to survive the trek through the "valley of death", represented by the negative cash flow to the enterprise as the product is brought to market (Figure 7.5).

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[19] SEAB (1995b, p. 47).

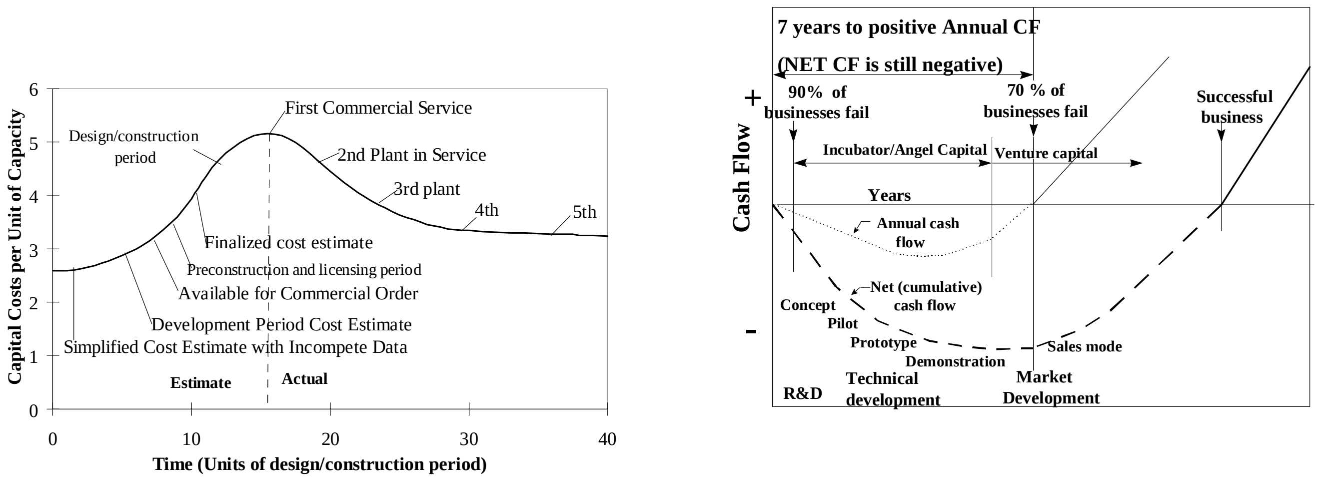

Figure 7.5: The "Mountain of Death" and "The Valley of Death" associated with the technological innovation process. Note that positive annual cash flow does not assure business success; 70 percent of businesses still fail at this point. Net Cash Flow is still negative when annual cash flow turns positive. Sources: “Mountain of Death” is from the Electric Power Research Institute; “Valley of Death” is from Helena Chum, NREL, and Irvin Barash, VenCom Management, Inc., personal communications. See also, Mitchell (1995).

This cost barrier can be surmounted. Volume production provides economies of scale, generates experience in manufacturing, installation, and operation, and opens new opportunities for incremental technological improvements—all of which lead to lower costs. If the needed growth in production is pursued solely through high-value niche markets, however, the cost-reduction process will often be so slow that it will be difficult to attract significant financial resources for product and market development. Successful commercialization often requires strategies to speed up the cost reduction process by accelerating early market development.

There is a consensus among policymakers that government support for long-term R&D is appropriate and necessary. Economists point out that innovation is the single most important source of long-term economic growth, with returns on investment in research and development being several times as high as the returns on other forms of investment. Yet private firms are unable to appropriate the full benefits of their investments in long-term R&D and thus tend to underinvest in it. These factors compel public support for long-term R&D to promote economic well-being. Over the last half century, public support for science has made the United States the world's preeminent scientific power.

In many cases, it is possible for private firms to appropriate the benefits of their investments in near-term R&D and demonstration and commercialization activities, despite the risks involved. In principle, once a new technology is proven, there should be entrepreneurs willing to accelerate its commercialization by absorbing the costs of buying down its price (e.g., by forward pricing of the product) if there are good prospects for cost reduction and a clear large and profitable market opportunity for the technology at the target price. The potential role of energy service companies in the restructured energy industry could be particularly important.

Box 7.3: Pasteur's Quadrant

A half century ago Vannevar Bush articulated in *Science, the Endless Frontier* the paradigm that all technological innovation is rooted in basic research conducted without thought of practical ends. He argued that basic research becomes a dynamo that enables economic progress when applied research and development convert its discoveries into technological innovations. This linear model of technological progress—flowing from basic research, to applied research and development, and on to production or operations—has guided science and technology policy planning for much of the post-World War II era. Bush also expressed the belief that the creativity of basic science will be lost if it is constrained by premature thought of practical use, and that applied research invariably drives out pure if the two are mixed.

It is now known that the relationship between basic research and technological innovation is far more complex than is suggested by this linear model. In the ongoing science and technology debates about this linkage, an important insight has been provided by Donald Stokes in his new book *Pasteur's Quadrant: Basic Science and Technological Innovation* (Brookings Institution Press, 1997). Stokes has shown that, contrary to the common view, fundamental research is often motivated by considerations of use as well as curiosity. His premier example is the fundamental research carried out by Louis Pasteur, who wanted both to understand and to control the microbiological processes he discovered. Irving Langmuir's desire to understand and to exploit the surface physics of electronic components, and John Maynard Keynes's interest in both understanding and improving the workings of modern economies are other examples.

This new insight is timely in light of the growing interest in harnessing science for the technological race in the global economy. Stokes suggests that Bush's one-dimensional model of technological progress be replaced by the two-dimensional matrix shown below. The linear model would involve only Bohr's Quadrant (research driven by the quest for fundamental understanding, as epitomized by the physics research of Niels Bohr) and Edison's Quadrant (research guided solely by applied goals, without seeking a more general understanding of the phenomena in the field, a good characterization of the research of Thomas Edison). Stokes adds to the array Pasteur's quadrant: research that seeks to extend the frontiers of understanding but is also inspired by considerations of use. (Stokes also suggested that his fourth quadrant might be named Peterson's Quadrant after Roger Tory Peterson, whose *Guide to the Birds of North America* is an example of curiosity-driven research about a particular thing, inspired neither by the goal of fundamental understanding nor by the goal of use, although he felt that this is too limited an example to warrant the name.)

Stokes' insight is important for the deliberations of the PCAST Energy R&D Panel because of its findings that many of the energy-technology programs at DOE could be markedly improved if buttressed by research activities addressing fundamental questions raised by technology developments. Contrary to the Bush view that consideration of use implies that such research would be applied research, which would tend to crowd out fundamental research, the Stoke's model suggests instead that adding consideration of use as a driver would expand opportunities for fundamental research, while providing needed inputs to technological development activities.

Stokes's Quadrant Model of Scientific Research

Research Is Inspired By:		Considerations of Use?	
		No	Yes
Quest for Fundamental Understanding?	Yes	Bohr's Quadrant	Pasteur's Quadrant
	No	?	Edison's Quadrant

Despite the theoretical appeal of relying fully on the private sector for commercialization, there are substantial barriers limiting the commercialization of many new energy technologies under present and prospective market conditions. These barriers, which include the following, are particularly troublesome for environmental energy technologies (EETs):[20]

- Financial support for developing and commercializing new energy technologies is difficult to obtain, because (1) energy prices, particularly for natural gas, are so low as to pose extraordinarily stiff competition for any new energy technology; and (2) energy is a commodity with very thin margins and substantial risks of price drops. This contrasts with the pharmaceutical and semiconductor industries where there are large margins on innovative products that encourage venture financing, and where aggressive pricing to pull costs down the learning curve is routine

- Large companies normally have many investment opportunities, so the (internal) competition for financial and other resources is intense. The natural tendency is to fund those technologies that are less risky, nearer term, and incremental. For new technologies to be funded, they must therefore offer a commensurate high level of risk-weighted returns.

- Entrepreneurial start-up companies with only one technology option (or a limited number) are more likely to "bet the company" on the development of a technology than large companies are, but they have limited financial resources to commercialize the products they are developing and have difficulty attracting external financing.

- Infrastructures in which the new technologies would be used are often not well developed. For example, low temperature fuel cells can be deployed at very small scales in buildings as distributed electric-power sources, but the current electric-power generating industry is organized around central-station power plants and is not well suited to handle distributed systems.[21]

- Innovative energy-supply and end-use technologies are often more capital intensive (and less fuel intensive) than conventional technologies, which can deter potential users.

- The environmental benefits of EETs, which are the focus of R&D programs, are generally undervalued in the market, reducing private incentives to develop or invest in these technologies.

Thus, for technologies that provide public goods – such as reduced pollution or increased safety – in addition to private benefits, *temporary* government support for demonstration and commercialization is often warranted. This would be the case for EETs that provide public goods in the form of a cleaner and safer environment. The government has a stake in promoting the demonstration and commercialization of technologies that provide such public goods and integrating these demonstration and commercialization activities with the R&D process so as to optimize the efficacy of the R&D and increase the return on the public investment.

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[20] These are energy technologies--such as many renewable energy technologies, fuel cells, and a wide range of energy-efficiency-improving technologies--that are characterized by a high degree of inherent cleanliness and safety.

[21] In the case of fuel cells, natural gas is an effective and efficient fuel for which there is a well developed and comprehensive infrastructure.

The many barriers to commercializing EETs noted above show why government support will often be needed to help launch EETs in the market. Incentives for providing this assistance should be:

- effective in quickly establishing reasonably large production and market demand levels for EETs, allowing companies to scale up production with some confidence that there will be a market to compete for;
- efficient in driving down costs as cumulative production increases;
- minimally disruptive of existing energy-financial systems during the transition period;
- able—within available financial resources—to support a diversified portfolio of options;
- easily and transparently administered and require minimal administrative overheads; and
- temporary, with "sunset" provisions built into the commercialization incentive scheme *ab initio*, but long enough to catalyze the desired activity.

It is highly desirable to find ways to provide commercialization supports without tapping scarce resources from R&D programs. This will be politically difficult if all the resources are "in the same pot," since commercialization programs tend to be politically more glamorous than R&D programs.

A wide variety of policy instruments for providing commercialization incentives are available. Past experience shows, quite simply, that *you get what you ask for***.** Policy tools used in the 1970s and 1980s included loan guarantees and investment tax credits, which generated loans and investments, respectively, but—with a few exceptions—did relatively little toward creating viable industries, developing energy technologies, or even generating energy.

In the late 1980s and early 1990s, the focus turned toward performance-based incentives such as guaranteed prices for energy or energy production credits. Guaranteed energy prices or energy production credits give vendors a high degree of confidence that there will be a market for their product and can be effective in quickly building up large capacities of new energy technologies. But such instruments are inefficient in driving down prices and can sustain technologies (e.g., grain-derived ethanol[22]) that have poor prospects of ever being competitive. Moreover, as capacity for a particular technology grows, the required subsidy can quickly become very large, crowding out available public sector support for commercializing other technologies. However, where it is not practical to introduce more efficient incentives, production credits for EETs might be considered.[23]

A carbon tax has been frequently suggested as an instrument for encouraging the use of low-carbon energy technologies. (Of course, such a tax would encounter significant political opposition.) However, to be effective in directly helping commercialize new technologies, a carbon tax may have to be so large that it would significantly change the workings of the overall energy economy, and is, therefore, a policy with implications that are beyond the scope of this report. The same is true for international and national carbon cap-and-trade systems. While these mechanisms may be effective in generating a range of low cost responses, they may not provide adequate incentives for the introduction of new technologies in all

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[22] In contrast to ethanol derived from grain, ethanol derived from cellulosic feedstocks, the focus of the DOE biofuels R&D program, has very good prospects for being competitive with oil.
[23] The Renewable Electricity Production Incentive enacted in the Energy Policy Act of 1992 may be a useful example..

instances because they do not directly address the gap between the costs of first-of-a-kind and mature products.

Auctions are one option for directly supporting the commercialization of qualifying technologies. An auction selects, through a bidding process, the most competitive options in each qualifying technology category. A subsidy makes up the difference between the winning bid and the market energy price. To be effective in reducing costs, a series of auctions is needed over a number of years to provide corporate planners a consistent market to target and scale up production for.[24] An example of how auctions work in electricity markets is provided by the Renewables Non-Fossil-Fuel Obligation in the United Kingdom, in which the price of renewable offerings was cut in half in just six years. The cost of the program is paid for by consumers in the form of higher electricity prices, which has amounted to less than a 0.5 percent increase.

Renewable Portfolio Standards (RPS) are another option intended to maximize the use of market forces in establishing renewable energy industries, particularly in the context of electric industry restructuring.[25] Under an RPS each retail supplier of electricity must provide a specified[26] minimum percentage of qualifying renewable energy technology in its portfolio of electricity supplies. Individual obligations would be tradeable through a system of renewable energy credits (RECs)—created when a kWh is generated from a renewable source of energy. Retailers could choose among owning their own renewable energy facilities to obtain RECs, purchasing them from other suppliers of renewable electricity, or purchasing them from a broker. The administrative requirements of government are less under a RPS than under a series of auctions, because the market rather than an administrative process would choose winning options and suppliers. The RPS standard could be generalized into an Environmental Energy Portfolio Standard (EEPS) aimed at promoting the commercialization of a range of new energy technologies that are able to meet specified local, regional, and global goals in relation to environment, energy-supply diversity, and security.

The market mechanism envisaged for an RPS is very similar to that for the cap-and-trade system for reducing SO_2 emissions written into the 1990 Clean Air Amendments. Early predictions had been that cutting SO_2 emissions 50 percent as required under the Clean Air Amendments would cost $1,500 to $2,000 per tonne. Instead, with an open market created for SO_2 emissions permits (at half the original emissions level) industries have been able to cut emissions for only $100 to $150 per tonne. This success reflects the ability of firms to choose the least costly option for complying with the well-defined environmental requirement. An RPS is similarly expected to have a very modest impact on rates paid by consumers, as in the case of the experience with the Renewables Non-Fossil-Fuel Obligation in the United Kingdom.[27] In summary, that experience indicates that auctions and tradeable credit systems tend to be

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[24] Wiser and Pickle (1997).

[25] Rader and Norgaard(1996).

[26] The government would decide on the number of RECs required in relation to the total electricity sales by each retailer, based on renewable energy resources in the region, policy objectives, and potential costs. Separate requirements would likely be necessary for different classes of renewables (e.g., wind and photovoltaic sources) to account for different levels of technological maturity. The number of RECs in a given technology class might start at a low level, and increase over time as renewable energy experience increased.

[27] The Tellus Institute (Steve Bernow, private communication, August 1997) has estimated the effect of a national RPS mandating that 4 percent or 8 percent of electricity generation should be from non-hydroelectric RETs by 2010 to be an increase in the average electricity price by $0.0004/kWh or $0.0017/kWh (0.6 or 2.6 percent of the retail electricity price), respectively. These estimated cost penalties are probably higher than they would actually be, because they were derived using the NEMS model of the Energy Information Administration, which does not adequately take into account cost reductions from both learning and technological improvements in RETs that are expected in this period.

efficient, whereas investment tax credits and ad hoc technology demonstrations have often not been efficient mechanisms.

Other mechanisms are under widespread discussion for addressing public benefits at risk due to structural changes in the electricity sector. Particularly notable is the Systems Benefit Trust modeled after similar mechanisms used in the telecommunications industry and others. A Systems Benefit Trust or similar mechanism could provide support for public benefits (e.g., energy assistance for low-income households, customer service protections, energy efficiency programs, R&D, etc.) that would otherwise be neglected in a restructured competitive electric industry. Such a Trust might be used in conjunction with an RPS or an EETS.[28]

Temporary public funding in launching new industries based on a few key new EETs[29] could be very effective in supporting multiple energy policy goals. These technologies would sharply reduce local and regional air pollutant emissions without the need for complicated end-of-pipe control technologies, make possible deep reductions in CO_2 emissions, and increase energy supply diversity—both for US markets and for developing country and other international markets that would be served by US exports of such technologies.

While technology commercialization tends to be more costly than R&D, overall costs for commercializing a diversified portfolio of EETs using efficient, market-based instruments for buying down their prices (e.g., auctions or EEPS) should be relatively modest. Many EETs are small-scale and modular, which also reduces the high costs of "scaling up" in the development process. The high degree of inherent safety and cleanliness of such technologies also minimizes requirements for improving safety and environmental performance. The cumulative costs of buying down the prices of such new technologies via progress along learning curves can often be low relative to learning costs for large-scale technologies.

The amounts of money involved are significant but by no means impractical or disproportionate to environmental benefits. For example, the World Energy Council has estimated that to be competitive with conventional options, various solar energy technologies may need, in addition to support for R&D, cumulative subsidies at the global level of the order of $7 to $12 billion to support initial deployment until manufacturing economies of scale are achieved.[30] For the U.S., the total investment required to commercialize four different fuel cell technologies for stationary applications has been estimated to be $2 billion.[31] Efficient market mechanisms could be similarly used in aggressive Federal procurement to buy down prices of environmental energy technologies.

Recommendation: **The Panel recommends that the nation adopt a commercialization strategy to complement national R&D work in specific areas. This strategy should be designed to reduce the prices of these technologies to competitive levels and should be bound by cost and time.**

The Panel does not make a recommendation as to the source of funds for such an initiative. We do believe, however, that such a commercialization effort should be designed to be very efficient in allocating funds to drive prices down, minimally disruptive of energy-financial systems, and temporary.

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[28] Cowart (1997).

[29] This could include wind turbines, photovoltaic systems, biomass gasifiers for power generation and fluid fuels production, fuel cells for transport and stationary combined heat and power generation and associated enabling technologies such as various electrical and hydrogen storage technologies, biomass production technologies, and underground sequestration of the CO_2 produced as a byproduct of producing hydrogen or hydrogen-rich energy carriers for use in fuel cells.

[30] WEC (1994).

[31] Penner et al. (1995a, 1995b).

INTERNATIONAL ISSUES

Most of the growth in energy use over the next century will take place in developing countries. As described at greater length in Chapter 1, this prospect raises a number of concerns and opportunities, as follows:

- Economy: Energy is fundamental to economic well-being and improvement in the quality of life in all countries, but especially in relation to the prospects for economic growth in the developing countries and for improving the lot of the world's more than two billion rural poor (who lack access to even minimal supplies of electricity and other modern energy forms). The inevitable and desirable push to improve the economic lot of the people of the developing countries represents both an energy challenge and an immense opportunity for marketing energy technologies appropriate to this purpose.

- Environment: Energy-linked pollution is a serious problem in both the urban and rural sectors of most developing countries, and the expected rapid growth of developing-country energy use will be adding ever more significant increments to the already very large GHG emissions of the industrialized countries. The resulting disruptions of local, regional, and global environmental conditions and processes pose threats to economic well-being as well as to human health and environmental values.[32] In most developing countries, moreover, there are few environmental controls, environmental regulatory systems tend to be weak and ineffective, and there is generally limited interest in spending economic-development funds on environmental protection. This situation, too, is both a challenge and an opportunity.

- Security: Competition for and possible conflict over energy resources—such as oil in Asia or the Middle East—is a significant and potentially growing security concern, as are social and political instabilities that could arise from economic and environmental adversity aggravated by inadequacies in energy options.[33] So, also, is the need to minimize the potential links between nuclear energy and nuclear weapons. The confluence of challenge and opportunity in these security issues is, again, obvious.

As the world's largest consumer of energy and of oil and the world's largest emitter of carbon dioxide, the United States has a special responsibility to lead in addressing these energy-related economic, environmental, and security concerns by demonstrating—particularly for developing countries that are just beginning to build their energy infrastructures—that it is possible to shift to clean, secure, and sustainable energy systems while maintaining or improving economic growth. The development and deployment of improved energy technologies along the lines described in Chapters 3 through 6 clearly will be crucial to this effort.

The actual magnitude of the contributions toward these ends that new U.S. technologies are able to make on a global scale will depend in substantial part on how this country manages the opportunities of international collaboration and the challenges of international competition in relation to energy research, development, demonstration, and commercialization. Complementing the considerations of international

[32] For example, tropical and subtropical regions could suffer substantial reductions in agricultural output due to global warming. Rosenzweig and Parry (1994).

[33] For example, increased energy inputs could raise agricultural productivity and reduce the need to expand agricultural lands; similarly, energy might help reduce shortages of water.

collaboration and competition outlined in Chapters 3 through 6 in relation to specific energy options, the two subsections that follow address some crosscutting aspects of these issues.

With respect to collaboration and competition alike, it needs to be emphasized that the specific forms of energy technologies best suited to developing country contexts will often differ from those that fit industrialized-country contexts. Lower wage rates, different resource endowments and environmental circumstances, different workforce characteristics, and the attractions of maximizing local content of equipment may all require engineering changes in specific energy systems compared to industrialized-country practice. Success in the international arena will require that such differences be understood and addressed by U.S. energy R&D efforts in the public and private sectors alike.

Collaboration

There are numerous opportunities to collaborate in international R&D efforts as well as to facilitate international joint ventures to accelerate technology commercialization. These opportunities range from small staff exchanges to support for mega projects in which international collaboration is essential to marshal sufficient resources for the R&D. Much more attention should be give to these possibilities for collaborative work between the United States and developing countries, particularly in such areas as: applications development (especially for technologies that can leverage productive economic activities and/or meet needs in rural areas); small scale pilot projects and hands-on training; codes and standards development; technology and policy analysis and tool development;[34] education and training; R&D staff exchanges; technical assistance (including to multilateral banks and NGOs); and many others.

Such collaborations are particularly important in renewable energy and energy efficiency where the industries are often embryonic, there is no well developed recipient industrial structure, and the technologies face myriad market distortions and challenges. In these circumstances, collaborations can help the United States to develop in-country partners and better understand market needs. International collaborative efforts also play a critical role in international nuclear safety issues, where the key point is to share unparalleled U.S. expertise and experience.

Important roles in international collaboration in energy R&D can be played by USAID, DOE, and the national laboratories. USAID has long played a lead role in building in-country institutional, technical, and human capacity through training programs, technical assistance, development projects, and other supports. In collaboration with DOE and the national labs, USAID can strengthen the technical side of these activities. USAID and DOE can also play an important facilitating role in developing collaborative R&D, and opening doors for industry joint ventures between U.S. and developing country companies.

U.S. international activities in energy research, development, demonstraion, and commercialization can be substantially leveraged by working with the Multilateral Development Banks (MDBs). The MDBs play an important role in promoting structural reform, developing infrastructure, and supporting a wide range of development activities in developing countries. The MDBs have not, however, generally supported innovative environmental or energy technologies because their operating arms often consider the assumption of any risk on behalf of their developing country clients as in violation of their fiduciary responsibilities.[35] This greatly limits development and deployment of EETs. Just as R&D is linked closely to demonstration and commercialization in the United States, so too are they closely linked in international

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[34] This might include such issues as distributed utility analysis, village minigrid technology development, and regulatory restructuring, to name only a few.

[35] The Global Environmental Facility is a particularly notable exception.

markets. The U.S. should work with the MDBs wherever possible to institutionalize funding mechanisms in support of R&D as well as precommercial or early commercial EETs, and to develop mechanisms to encourage the MDBs to accept greater risk in deploying EETs. Given the magnitude of funding flows through the MDBs, redirecting even a small portion of this funding could have major impacts.

Competition

Energy technology firms worldwide increasingly see the developing countries as critical markets for their products. Various estimates place the developing country demand for electric-utility equipment alone at as much as $100 billion per year. There are similarly large markets for energy and energy-related technologies in the transport, industry, and buildings markets. In some cases, energy-technology deployments may directly assist market penetration by associated technologies, as in the case of PV or wind technologies in rural areas linked to downstream applications such as communications and information technologies, small-scale manufacturing equipment, household lights and appliances, agricultural equipment, and so on; the manufacturer that can provide a low-cost, effective energy source can integrate it with other system components and open large potential markets.

Countries competing in international energy-technology markets have used various combinations of domestic and export market strategies to boost their competitiveness. Domestically, for example, several countries have established strong market pull for innovative technologies (e.g., for renewable energy) in order to provide their firms good cash flow, reduce company risk, generate funds for company RD&D, and assist scaleup of manufacturing in order to drive costs down the learning curve. For export markets, several industrial countries are providing pilot demonstrations, training, concessionary finance (e.g. preferential terms such as covering half of the cost of the equipment with a loan at 0 percent interest for 10 years), and other supports.[36] Some exporting countries have assisted importing-country officials to write standards and regulatory processes, which then tend to favor their companies and equipment and lock out competitors. (See Chapter 6, Wind.)

Potential U.S. responses to these challenges include domestic, technical, and trade components. Domestically, developing strong market pull in the United States for innovative energy technologies, as discussed in the section above, would assist manufacturing scale-up and drive costs down, and would assist cash flow for innovative companies. By using efficient market-driven mechanisms, such as those described above, to bring costs down to levels at which energy technologies can compete in restructured competitive energy markets, U.S. firms will maintain their competitive drive and develop highly competitive technologies; this may be in contrast to some foreign firms that have benefited from relatively high guaranteed energy prices or other assured opportunities that do not as strongly hone their competitive edge or their technology performance..

Technically, a U.S. emphasis on advanced energy technology R&D can greatly strengthen U.S. competitiveness in the mid to long term. Government/industry/national-laboratory/university partnerships can be an important vehicle for regaining and/or maintaining the scientific, technical, and market leadership of the United States in energy technology.

International trade issues pose particular difficulty for the United States; the United States does not want to resort to the type of trade tactics employed by some competitors. In the long term, a U.S. emphasis

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[36] The United States has also engaged in a number of these activities, often on a more ad hoc basis than may be desirable. The United States has generally not engaged in concessionary finance, except as an occassional response to that of competitor nations.

on advanced technology R&D can lead to a strong competitive advantage that can overcome much of the foreign competitors' advantage due to public support. In the near to mid term, while these technology development efforts are underway, the challenge of foreign concessionary finance and other public supports should be addressed, where necessary, by more aggressive and proactive responses by U.S. trade agencies. Such responses may be particularly important in order to maintain a viable U.S. company base in these innovative energy technologies.

Recommendation: **The Panel recommends that the government and government/national-laboratory/industry/university consortia should engage strongly in international energy technology R&D and development and commercialization efforts to regain and/or maintain the scientific, technical, and market leadership of the United States in energy technology. This should include increased R&D (particularly in collaboration with developing countries), temporary support for demonstration and commercialization activities where appropriate, and aggressive and proactive responses to foreign export promotion activities where necessary.** USAID with DOE and the national laboratories can play a key role in supporting the full range of activities noted above to develop and field test environmental energy technologies and facilitate their commercialization.

It is important to recognize that international R&D collaborations, market development, and responding to foreign export promotion are essential to the technology development and growth of U.S. energy companies, which face stagnant markets at home and aggressive public-private partnerships abroad. Many of the most innovative U.S. entrepreneurial companies simply do not have the resources to play on such an uneven playing field. The actions recommended here to help level it not only will help improve the competitiveness of U.S. companies but, in so doing, will help address the wider economic development, environmental, and security challenges discussed throughout this report.

Finally, for international programs to be effective, trusting relationships with the foreign partner are crucial. These can only be developed by directly and frankly evaluating the technologies and programs on merit, and by demonstrating that the United States is a reliable partner. To be a reliable partner requires meeting funding commitments consistently and having a stable funding base to operate on over the mid-term, measured in probably at least 5-year periods.

R&D MANAGEMENT ISSUES

In the course of this study, the Panel observed a number of problems in DOE management of R&D, including: "stovepiping" of programs and a frequent lack of effective coordination;[37] micromanagement of R&D programs; burdensome oversight; limited technical skills among a significant number of DOE staff, resulting in misdirection of some R&D programs; and sometimes a lack of clear leadership. There were also many examples of good management and thoughtful leadership under difficult conditions. These are not new observations; the SEAB Alternative Futures[38] and SEAB Strategic Energy R&D[39] studies reported similar findings. As far as the Panel has been able to tell, however, DOE actions in response to the findings and recommendations of these past Task Forces have been insufficient and major management deficiencies remain.

[37] Stovepiping refers to the excessive narrowness of DOE programs and the tendency to not effectively coordinate activities across program boundaries, such as between energy efficiency and fossil energy, or between nuclear energy and nuclear-energy-related programs outside of DOE's applied energy technology R&D programs.
[38] SEAB (1995a).
[39] SEAB (1995b).

The Panel brought to its task a diverse membership—corporate leaders, Federal department managers, national laboratory researchers, and university professors—with broad experience in R&D not only in the energy field but in others. Although we did not conduct detailed reviews of specific internal processes and so are unable to make precise prescriptions, we do make several broad observations and recommendations below that we believe could significantly improve the management of DOE energy R&D resources.

We want to emphasize at the outset that the need for improvement in some aspects of DOE's R&D management should not detract from the central message emerging from our study, which is the following:

> Energy R&D coupled with demonstration and commercialization is vital to the future of the United States and the world, and is the most effective way to meet the energy-linked economic, environmental, and security challenges that we face.

Simply to cite "management problems", moreover, implicitly paints too broad and bleak a picture. There are many capable and hardworking staff at DOE who are committed to resolving these national energy challenges. They work long hours under great pressure in an environment of intense scrutiny and non-stop second-guessing. And along with some failures, they have also overseen the R&D of numerous highly successful technologies, which have already provided a return far greater than the total Federal investment in R&D, as noted by the SEAB Strategic Energy R&D Study.[40] DOE has also made some efforts to correct problems identified by SEAB Alternative Futures and Strategic Energy R&D Studies, but significant problems persist.

The roots of the observed management difficulties run much deeper than conditions in DOE alone. As noted by the SEAB Alternative Futures and Strategic Energy R&D studies, many of these problems begin with congressional micromanagement of programs, earmarking of budgets, and dramatic congressional shifts in budget levels and directives to DOE. These have led to an embattled agency that is cautious and bureaucratic in self defense. Although many competent and technically skilled staff remain, these factors have contributed to an ongoing loss of highly capable individuals retiring or moving to positions elsewhere.

Congressional directives also sometimes directly conflict with sound management of programs. Congressional support is driven substantially by constituency interests. As a consequence, industry representatives must repeatedly meet with Congress to maintain ongoing support even for cost-shared programs. This situation places a particular burden on innovative entrepreneurial firms, which do not have the resources to spare for staff to frequently meet with Congress. Congressional shifts in budget levels and pullback of "uncosted obligations"[41] make the development and management of multiyear cost-shared projects with industry very difficult. This reduces the ability of DOE to work with industry even though such partnerships are essential if the R&D is to be most effectively done, market relevant, and quickly commercialized, while leveraging Federal investments.

There is no question that the above difficulties have made it difficult for DOE to operate in a strategic manner in the energy R&D area. However, such congressional attention is common to many

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[40] SEAB (1995b, Appendix 3).

[41] "Uncosted Obligations" are typically funds that have been set aside for cost shared work with industry that have not been "spent" in the year that they were appropriated. The typical reason for this is that uncertain annual funding cycles force DOE program managers to accumulate funds for an entire multiyear project before they can commit to it with industry. To do otherwise risks the loss of private company investment and ability to deliver on contracts and pay off loans, etc. This erodes the credibility of the government as a reliable partner in R&D.

technical agencies, some of whose leaders have nevertheless managed to carry out many, if not all, of their key programs in a way that satisfies congressional desires while preserving and advancing the long-term vision-driven strategy of the agency.

Federal and Departmental Leadership

The challenges are national and global in scale. This requires a national strategy and Federal leadership forged in concert with state and local government, industry, labor, public interest groups, universities, and other stakeholders. Resources must be similarly mobilized nationally, in concert with these groups. Creation of a clear, strategic, long-term plan—whose implications can logically be traced through to the necessary programs and projects, and thus made clear to congressional committees and other stakeholders—is essential.

Energy R&D and energy use affect and involve many Federal and State agencies, including those dealing with agriculture, commerce, defense, energy, forests, housing, industry, international, science, transport, etc. This requires careful coordination and cooperation between agencies, but also offers substantial win-win opportunities.

There is a need for clearer leadership on energy matters within the Department of Energy itself, with accountability for the energy technology programs residing with a single individual reporting directly to the Secretary. In this connection, the fourth recommendation of the SEAB Strategic Energy R&D Study stated:[42]

> *The Task Force recommends that overall responsibility for energy R&D portfolio strategy, budgeting, management, and integration over existing programmatic divisions be given to a single person reporting directly to the Secretary of Energy, at either the Under Secretary or Deputy Secretary level. No new layers of management should be created.*

Although the energy science and technology programs currently report to the Deputy Secretary, so, too, do the Power Marketing Administrations, Energy Information Administration, Defense Programs, and NonProliferation and National Security Programs. Under these circumstances, it seems unlikely that sufficient focused attention can be given to the energy technology programs to resolve the management problems. There remains the need for a single clearly defined, accountable authority with specific duties to resolve the DOE energy technology management problems. This domain includes both energy technology and fundamental energy research activities at DOE.

Recommendation: **The Panel supports the underlying logic and substance of this position and recommends it to the President and Secretary of Energy: there should be a single person responsible for energy science and technology R&D reporting directly to the Secretary. This includes energy technology programs and fundamental energy-related research in the DOE Energy Research Program.**

National Laboratories

The importance of the national laboratories in working with industry and universities to address our national challenges should be recognized. National laboratories are often uniquely able to provide

[42] SEAB (1995b, p. 49).

highly capable multidisciplinary teams using sophisticated tools and techniques to conduct leading edge energy R&D. The importance of the national laboratories was emphasized by the SEAB Alternative Futures and Strategic Energy R&D studies and also observed by the Panel. National laboratory management was reviewed in detail by the SEAB Alternative Futures study and will not be repeated here. Discussions with a variety of individuals inside and outside the national laboratory system identified several problems, leading the Panel to make the following recommendations.

Recommendation: **Where possible, lead laboratories should be named in major R&D areas according to their technical and programmatic strengths. Further, laboratories should be treated by DOE as integrated entities, not—as is often currently done—as a collection of independent projects which DOE program managers control independently**. The Panel found several instances of activities being scattered across multiple laboratories with laboratory infighting over the fragments.

Partnerships

As already noted, it is necessary to link the applied technology R&D with fundamental research and with demonstration and commercialization activities in order to conduct the R&D most effectively and to ensure that the R&D is appropriately targeted for the market. In turn, this requires in most cases that the work be done through equitable industry/national-laboratory/university partnerships among technically qualified peers. Each of these partners has strengths and weaknesses.

Industry is strongly market driven, but may have insufficient research capability. Industry has sometimes been allowed to be the primary driver of program direction, but the market pressures they face can then lead to an excessively near-term focus. National laboratories provide strong basic and applied R&D capabilities and an exceptional capability for integrating complex R&D through mutidisciplinary teams. They can counterbalance the industry near-term focus, but as wholly owned and controlled contractors to DOE their advice is sometimes not valued by DOE staff; further, they have a tendency to focus on research to the exclusion of market considerations (which is neither their expertise nor their appropriate domain). Universities provide particular strengths in long-term research, but in many cases, universities have not been adequately supported in recent years as energy R&D funding has been cut back, reducing their role and depth; they also have a tendency to do research without thinking sufficiently about commercial applications. Collaborating in industry/laboratory/university partnerships, these entities can mutually counterbalance each others' weaknesses and strengthen overall program direction and performance.

Recommendation**: Federal energy R&D efforts should make extensive use of industry/ national-laboratory/university partnerships to provide overall guidance for the Federal programs and to conduct the R&D efforts**.[43]

External Oversight

To effectively direct R&D, taking into account the critical linkages between basic research, demonstration and commercialization, international concerns, and crosscutting issues such as carbon, is generally beyond the skills of a single individual, no matter how talented. The DOE Industries of the Future program, among others, has made use of industry/national-laboratory/university technical peer review and oversight committees to provide overall technical direction to those programs, including the

[43] To avoid conflicts of interest, the program guidance and the conduct of the R&D should be in the hands of separate, independent groups.

development of technology roadmaps. This may be a broadly applicable model for the applied technology programs. DOE staff would then serve as facilitators and administrators, charged with minimizing bureaucratic overhead, and relying primarily on these external oversight committees for technical direction.

Recommendation: **The Panel recommends that overall R&D technical direction make extensive use of industry/national-laboratory/university technical oversight committees, with DOE staff serving as facilitators and administrators.**

Recommendation: In addition, **formal external peer review of all programs should be done every 1 to 2 years, but not more frequently. The numerous[44] reviews now held, combined with other reporting requirements, can take substantial time from research or related activities and should be reduced, with particular attention given to reducing the interim process-oriented reviews.**

Coordination

Better coordination is required at several levels in the Department of Energy: (1) between the fundamental research conducted within the Office of Energy Research (particularly its Basic Energy Sciences Program) and the applied energy technology programs; (2) among the applied technology programs; and (3) among all the energy-linked programs to address crosscutting issues.

Coordination Between Fundamental and Applied Technology R&D

For reasons rooted in history, DOE is the location of a substantial portion of the U.S. basic science programs. Some of these programs (e.g., high energy physics) are not mission-oriented but are part of the Federal basic science portfolio. Others were developed to address mission needs (e.g., some parts of Basic Energy Sciences do address energy mission needs).

The mission-oriented programs are intended to address fundamental science issues identified as important in the pursuit of the goals of the applied research programs, and as such belong in "Pasteur's Quadrant" of Stokes's quadrant model of scientific research (see Box 7.3). Such mission-oriented fundamental research can reduce technical risks in the applied technology programs and help ensure that the most promising avenues are being explored. In practice, however, maintaining productive interaction between DOE's applied research programs and its fundamental research programs has been an ongoing problem. The SEAB Strategic Energy R&D Task Force recommended, in this connection, "that improved coordinating mechanisms to facilitate cross-fertilization be implemented."

Despite such exhortations, little has happened to improve the situation. Inasmuch as exhortation has not been an effective approach in dealing with the problem, the Panel concludes that appropriate incentives are needed to bring about this integration.

[44] For example the Energy Efficiency and Renewable Energy Program lists 11 types of reviews: Market Scrutiny (continuously); Quality Metrics Peer Review (annually); Science and Industry Advisory Board Review (annually); Lab Operator Performance Self-Assessment (semi-annually); Laboratory Technical Division Reviews (annually); Multi-Laboratory Program Reviews (quarterly-annually); Initiated Science and Industry Program Review Meetings (annually); Other Standing Advisory Committees (periodically); Subcontractor Reviews (annually-continuously); Refereed Journal Articles (periodically); DOE Office of Program Analysis Reviews (periodically).

Recommendation: **The Panel recommends the following approach for making progress**.

- We believe the preferred approach to integration is cofunding and comanagment of a subset of the mission-oriented fundamental science programs in the Office of Energy Research and the applied technology programs. Under this approach, both budget planning and Request-for-Proposals (RfPs) would be written jointly by the relevant applied energy technology program managers and the managers of the appropriate energy- and energy/environment-linked programs in the Office of Energy Research, including relevant portions of Basic Energy Sciences, Computational and Technology Research, and Biological and Environmental Research (hereafter referred to simply as ER). Proposals would be jointly reviewed, with applied research partners reviewing them for relevance to their mission and the ER partners reviewing them for the quality of the science (as is done in the current Environmental Management Science Program); and the projects would be managed jointly.

- The incentive for comanaged/cofunded programs would be that a portion of the major applied research program budgets (rising to about 5 percent over three years) is dedicated to fundamental research, with matching funds from ER, for a total budget for targeted fundamental research equivalent to about 10 percent of the total applied technology funding. If the budget requests from both the applied research and ER Programs do not have such funds directed towards comanaged/cofunded programs in fundamental research, these amounts would automatically be lost in the budget allocation.

- The needed resources for these new fundamental research programs would not be provided by cutting existing programs. Rather these resources would be provided from new funds and from budgets that become available as programs normally "turn over," in both the applied research and ER Programs.

- Because of uncertainties about what does and does not work institutionally, these new integrated fundamental research programs should evolve over a three-year period, beginning in FY 1999. During this "experimental period" different variants on the approach could be tried. It might turn out that different arrangements work better in different areas.

If the overall approach described here for better coordinating the applied energy technology R&D and fundamental research programs cannot be successfully implemented, less desirable mechanisms such as sign-off by applied technology program managers on appropriate portions of the ER budgets or re-routing portions of the ER budgets through the applied energy technology R&D programs should be considered.

Our recommendation that ER aim more of its efforts at directly serving the needs of the applied energy technology R&D programs might raise concerns that the creativity of basic science will be lost if it is constrained by premature thought of practical use, and that applied research invariably drives out pure, if the two are mixed. What is being sought here, however, is not to redirect ER resources to applied research, but to augment ER support for fundamental research that could strengthen the ER/applied-technology programs. The net effect of this recommendation should be to expand, not diminish, the portfolio of fundamental energy-related research activities within the limits of overall budget constraints. In light of the growing interest among policy planners in harnessing science for the technological race in the global economy, the allocation of some ER resources to fundamental research programs that more directly serve the energy technology programs should add to the appeal of supporting basic research generally.

More strongly linking the fundamental energy research and applied energy research programs may also have several other potential benefits. The amount of funding going to universities from the applied technology programs is difficult to determine exactly, but appears to be in the neighborhood of 5 to 10 percent, compared to roughly 40 percent to industry, 25 percent to the national labs for in-house work, and 5 to 10 percent for DOE management.[45] In comparison, roughly 25 percent of the budget of the Office of Energy Research (and note that ER accounts for about 57 percent of the total energy R&D budget, see Figure 7.4 and Tables ES.1 and ES.2) goes to universities.[46] By linking more closely the fundamental science and applied technology programs, DOE will promote greater interaction among industry, national laboratories, and universities, and will help facilitate the formation of industry/national-laboratory/university partnerships. All of these closer linkages will strengthen the U.S. educational base and help produce the next generation of researchers needed to attain and/or maintain U.S. leadership in the science and technology of energy supply and use.

Coordination of Technology R&D Among the Applied Technology Programs

In addition to the possibilities just described for better coordination between applied energy technology and fundamental science programs, there are many opportunities for improving coordination among the applied technology programs themselves. Examples of such opportunities were provided above in the section on Project-Level Criteria, and include integrated gasification, fuel cell, gas turbine, drilling and excavation, and power electronics technologies.

In the course of its review, the Panel encountered a number of cases of effective ad hoc coordination of efforts across the traditional DOE "stovepipes" in circumstances where laboratory-level researchers had strong incentives to work across programmatic boundaries to get their jobs done. With modern communications, including the internet and powerful search engines, elaborate bureaucratic top-down coordination mechanisms may not be as necessary as they once were and those layers of management may be somewhat redundant.

Addressing Crosscutting Issues

The oft-noted "stovepipes" of DOE have not addressed crosscutting issues adequately, and such issues frequently reflect national concerns most directly. These include the oil-security problem, carbon emissions, and other environmental problems. Some areas of technology development, such as fuel cells, hydrogen, biomass energy, and others, are also fragmented across or blocked in part from reaching across stovepipe boundaries. The Panel notes that the same mechanism of a senior official with the Secretary's authority for coordinating energy R&D budgets and programs would solve this problem.

Recommendation: **Solving DOE's overall energy R&D coordination problem requires the leadership of a senior official carrying the clear delegation of the Secretary's program and budget authority for this area.**

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[45] About 20 to 25 percent of the total funding in the Energy Efficiency and Renewable Energy Budget also goes to grants, such as state activities, low-income weatherization, and others.

[46] As noted in Figure 7.4 and Tables ES.1 and ES.2, the budget of the Office of Energy Research—which contains all fusion energy R&D as well as Basic Energy Sciences, Biomedical and Environmental Research, and some other categories—contains about 57 percent of DOE's total energy R&D spending.

Micromanagement and Staffing

Micromanagement of both R&D and process was a recurring theme among those with whom the Panel spoke. As noted by the SEAB Alternative Futures and Strategic Energy R&D studies:[47]

> *As a function of the detail with which the Congress prescribes what should be done in the laboratories and the Congress's obsession with the issue of accountability, the Department is driven both to honor the prescriptions from Congress and to over-prescribe in order not to be at risk of failing to be super attentive to Congress's intentions.*

Micromanagement concerns include fragmentation of program activities across research areas and R&D institutions, increasing the difficulties of coordination; excessive program reviews and reporting requirements; and distribution of program funds in small quantities in some cases, increasing the overhead required to obtain funding for research. The Panel did not systematically collect data on these problems but heard extensive anecdotal evidence of it. Systematic collection of such data should be done by DOE as a natural part of ensuring effective management, including accounting for FTEs per dollar over time and benchmarking DOE against other R&D agencies, both public and private. A credible Management Information System for tracking management overheads and processes at DOE is badly needed.

The utility of DOE Field Offices was also raised by a number of people interviewed by the Panel. With modern communications and travel, there appears to be little that the Field Offices can do with respect to energy technology R&D and related management that could not also be done from DOE Headquarters more efficiently and with less bureaucratic and personnel overhead. At the same time, the Field Offices clearly add additional and often parallel layers of management that contribute little to the overall effort and give rise to a variety of miscommunications, confusion, and waste.

Recommendation: **The balance of work on energy technology R&D between the Field Offices and DOE Headquarters should be rationalized to minimize the problems described above, most likely by ending those activities by the Field Offices. If other considerations dictate continuation of energy R&D-related activities by the Field Offices, procedures should be greatly streamlined and staff given tasks that will not involve their interference with the necessary direct flow of management communication between the headquarters and the field.**

It is also important that DOE staff technical skills be strengthened through training, targeted hiring, and by rotating national laboratory staff and outside academic and industrial technical experts through DOE on a systematic basis as senior professionals with significant responsibilities for guiding program planning and policy. Mechanisms—such as the Intergovernmental Personnel Act—are available and should be systematically made use of to allow these outside experts to fill all of the same roles at DOE as Federal employees.

The Panel does not know what the appropriate staffing level should be for these programs. Programs vary in size and requirements, with some requiring more extensive outreach and coordination, some moving smaller blocks of funding, and some requiring more careful oversight of contracts. Some programs include field researchers in their FTE count (e.g., Fossil Energy) with only a fraction serving in a management role; other programs rely on national laboratory staff for significant management support but these staff do not appear in their FTE count. These and many other factors make it difficult to identify the

[47] SEAB (1995b, p. 38).

appropriate level of staff or to accurately measure current overheads. Nevertheless, the problems of micromanagement communicated to the Panel indicate the need for a careful review of DOE processes. It is important that DOE begin to track these management overheads in a consistent and credible way.

DOE has begun to address the staffing issue, with some downsizing planned in their strategic staffing plan. This should be encouraged, with a goal of management overheads being reduced to the lowest appropriate levels and comparable to the lowest levels found at other R&D agencies, again accounting for differences in program requirements. As this is done, it is important to maintain or even increase the technical and managerial quality of the staff through retaining staff on the basis of merit, technical and managerial training, and by rotating external professional staff through DOE, or by other means. Finally, the budget increases recommended by PCAST should not be accompanied by any increase in DOE Headquarters or Field Office staff. As discussed by the SEAB Alternative Futures and R&D studies, management overheads, including simplification of Federal Acquisition Regulations and DOE Acquisition Regulations, are probably the most significant cost area to mine for economy.

Work for Others

"Work for Others", as work for and with other public and private organizations outside of DOE is known, should be encouraged and supported—wherever appropriate to DOE's public mission—as an important means of leveraging DOE dollars and carrying out the Department's mission in energy R&D. However, DOE procedures and regulations are burdensome when doing work for and with outside groups. Changes are needed to streamline this process, including elimination of the DOE depreciation and overhead surcharges on such contracts (known as "added factor") and development of mechanisms to enable laboratory contracting under typical private sector terms such as "pay in advance" contracting; and other similar changes. The purpose is to get the work done as smoothly as possible, with satisfactory, but not infinite, measurement and accountability, and the minimum of unnecessary bureaucratic hand holding. It is important to question the reason for each procedure and step and to make sure that they add value to the process.

CONCLUDING OBSERVATIONS AND ONE FINAL RECOMMENDATION

Funding and managing the energy R&D needed to help address the energy challenges and opportunities of the next century are tasks not for the Federal government alone but for all levels of government, for industry, for universities, for the nonprofit sector, and for a wide variety of kinds of partnerships among entities in these different categories. The Panel's charge was to review Federal energy R&D, but we have been attentive to the ways in which the role of the government relates to and interacts with the roles of the other sectors. Our recommendations aim to focus the government's resources on R&D where high potential payoffs for society as a whole justify bigger R&D investments than industry would be likely to make on the basis of its expected private returns, and where modest government investments can effectively complement, leverage, or catalyze work in the private sector.

The funding increases we are proposing for Federal energy R&D, in order to better match the combined energy R&D portfolio of the public and private sectors to the energy-related challenges and opportunities facing the nation, appear quite large when expressed as percentage increases in some of the particular DOE programs that would be affected. But the increase in annual spending—amounting altogether to an extra billion dollars in 2003, compared to that in 1997, for R&D on all the applied-energy-technology programs together—is equal to less than one fifth of 1 percent of the sum that U.S. firms and consumers spent on energy in 1996; and it would only bring the Department of Energy's spending on applied-energy-technology R&D back to where it was in 1992, in real terms. The potential returns to society from this modest investment are very large. They can be measured in energy costs lower than they would otherwise be, oil imports smaller than they would otherwise be, air cleaner than it would otherwise be, more diverse and more cost-effective options for reducing the risk of global climate change than we would otherwise have, and much more.

If this is such a good case, why hasn't it been made and accepted before now? Actually the case has been made often before, by energy experts and by studies like this one. It has not been entirely heeded for a variety of reasons, most of them discussed above and many of them perfectly understandable. But perhaps the most important reason that the government today is not doing all that it should in energy R&D is that the public has been lulled into a sense of complacency by a combination of low energy prices and little sense of the connection between energy and the larger economic, environmental, and security issues that people *do* care very much about. In a way the low priority given to energy matters is reflected even in DOE itself, where energy is only a modest part of the Department's array of missions and there is no official responsible for all of the Department's energy activities and those alone.

What we have here is thus, in part, an education problem. There needs to be more public discussion and a growing public understanding of why energy itself—and therefore energy R&D—is important to the well-being of our nation and the world. In this the scientific and technological community has an obvious role to play, and we hope this report will be seen as a positive contribution to that. But the Federal government, led by the President, also has an important educational role to play, reflected in what is said and in what is done. As the last of the recommendations in this report, which was commissioned by the President, we therefore offer the following:

> We believe the President should increase his efforts to communicate clearly to the public the importance of energy and of energy R&D to the nation's future, and that he should clearly designate the Secretary of Energy as the national leader and coordinator for developing and carrying out a sensible national energy strategy, which of course includes not only energy R&D but much else.

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