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Energy Resources R&D Portfolio Analysis

Summary Report
of the
Vital Issues Panel Meetings
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EXECUTIVE SUMMARY

PROCESS

The Under Secretary of Energy of the U.S. Department of Energy (DOE), as Chair of the DOE Research and Development (R&D) Council, convened three expert stakeholder panels in the first half of 2000 to assess whether the DOE Energy Resources R&D Portfolio is likely to produce results capable of achieving significant progress toward seven strategic goals. The primary purposes of the portfolio analysis were to: (a) assess the adequacy of the Energy Resources R&D Portfolio in addressing strategic goals; (b) identify any gaps in the current R&D portfolio; and (c) indicate R&D and portfolio planning opportunities worthy of being explored; and (d) evaluate the relative contributions of R&D programs to achieving the strategic goals.

This assessment builds on a mid-1999 portfolio analysis, the findings of which are documented in a three-volume set of reports entitled, *Energy Resources R&D Portfolio Analysis.* The DOE Fiscal Year 2001 budget request includes a number of funding adjustments in response to these findings. Since mid-1999, the portfolio has changed significantly in some areas as a result of new Secretarial and/or Presidential initiatives, many of which address deficiencies observed by the mid-1999 analysis. The Energy Resources R&D Portfolio (February 2000) assumes these budget requests will be approved by Congress. This portfolio analysis is based on that same assumption.

The panels acknowledged the constructive changes made by DOE in the Energy Resources R&D Portfolio (February 2000). Many of these changes align well with the recommendations put forth by the mid-1999 portfolio analysis.

PORTFOLIO ADEQUACY

Assessments of adequacy of the Energy Resources R&D Portfolio was guided by the question of whether the portfolio is likely to produce results needed to make significant progress toward national strategic goals. Further definition of adequacy measures was provided by elaborating each of the goals in terms of subordinate issues and evaluating the portfolio with respect to how well the R&D activities seek to resolve each of these issues.

During the assessments, the focus was on the technical content of the R&D programs rather than on specific budget allocations. Thus, adequacy does not imply budget sufficiency, but merely that the correct topical areas are being pursued. Identification of important portfolio R&D gaps or opportunities often indicates budget insufficiencies or, perhaps, budget misallocations. A judgment of less than adequate in addressing a goal does not imply any evaluation of the quality of the R&D being performed in the portfolio.

Although none of the goals is judged to be addressed in a highly adequate manner, the Energy Resources R&D Portfolio adequately addresses two of the seven strategic goals:

- To improve the economic efficiency of the energy supply and end-use systems to enhance overall performance of the U.S. economy (Goal I - Economic Productivity); and

- To reduce the vulnerability of the U.S. economy to disruptions in oil supply (Goal II - Oil Vulnerability).

Three goals are addressed in a conditionally adequate manner:

- To ensure energy systems reliability, flexibility, emergency response capability, and risk management (Goal III - Systems Reliability);
- To reduce health and environmental impacts (Goal IV - Health and Environmental Impacts); and
- To stabilize greenhouse gas concentrations (Goal V - Greenhouse Gases).

Two goals are inadequately addressed:

- To cooperate internationally on global issues (Goal VI - International Cooperation); and
- To expand future energy choices (Goal VII - Future Choices).

The conditionally adequate and inadequately addressed goals deserve special attention.

Ensuring energy systems reliability, flexibility, emergency response capability, and risk management (Goal III): The overall adequacy would be improved by giving more attention to any adverse consequences of the interdependence of the electric power and natural gas systems. More importantly, although the other three subordinate issues associated with this goal (i.e., improving electrical power systems resiliency under deregulation and restructuring, improving natural gas systems resiliency, and increasing the resistance of energy systems to cyber and physical terrorism) are addressed reasonably well, these R&D activities are in the start-up phase and, as such, have not yet produced measurable results.

Reducing health and environmental impacts (Goal IV): Most of the R&D is focused on near-term challenges of meeting increasingly strict environmental regulations. Although the R&D activities in the current portfolio do extremely well in seeking to facilitate regulatory systems compliance while reducing the cost of mitigation, substantial improvements are possible in managing materials flows and in reducing nonregulated adverse impacts.

Stabilizing greenhouse gas concentrations (Goal V): Short-term issues, such as energy efficiency, are well addressed. The longer term issue of carbon sequestration is being addressed but in isolation from other energy system developments. Specifically, the longer term challenges of carbon capture, decarbonization of the energy mix, and lowering the carbon intensity of the economy are not being addressed adequately.

Cooperating internationally on global issues (Goal VI): This goal is the least adequately addressed goal overall. In response to the 1999 report by the President's Committee of Advisors on Science and Technology, *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation*, a multi-agency task force was established and a new initiative, the International Clean Energy Initiative, was proposed in the Fiscal Year 2001 budget request. The DOE portion of this initiative, if approved by Congress, should reduce significantly many of the deficiencies in the portfolio related to cooperating internationally on global issues. However, Panel II identified two specific actions that could improve the adequacy of the Energy

Resources R&D Portfolio related to the International Cooperation goal. One is expanding international technology partnerships and cooperative R&D agreements. Another is strengthening economic development or aid agreements with developing countries involving deployment of clean and efficient energy technologies.

Expanding future energy choices (Goal VII): The interactions between applied R&D and science programs are relatively poorly addressed compared to developing long-term energy technology choices. Nonetheless, Panel II pointed out repeatedly that the Energy Resources R&D Portfolio addresses well-defined short-term R&D needs much better than R&D activities with longer-term perspectives and time horizons.

RESEARCH GAPS AND OPPORTUNITIES

For six of the strategic goals, R&D gaps (and/or deficiencies) and opportunities were identified. Those representing R&D investments are put forth as priority gaps and opportunities as follows (in alphabetical order):

- advanced concepts for fuels and vehicles (i.e., post Partnership for a New Generation of Vehicles);
- advanced technologies to meet expected natural gas demand increases (e.g., emphasis on western hemisphere resources and methane hydrates);
- analysis tools and models applicable to deregulated electricity markets;
- indoor environmental quality, including air quality, air exchange and moisture level, artificial and natural lighting, and human productivity considerations;
- international technology partnerships and cooperative R&D;
- land and water impacts of materials flows;
- long-term greenhouse gas stabilization technologies;
- multi-attribute life-cycle analysis, including health and environmental considerations;
- non-petroleum energy supply options;
- on-board hydrogen storage systems; and
- real-time control and measurement, including intelligent power electronics, local demand management, and smart meters.

Each of these priority gaps and opportunities address one or more goals. How the seven strategic goals are addressed by these gaps and opportunities is summarized as follows:

Strategic Goals Addressed by Priority R&D Gaps and Opportunities

	Goal*						
	Economic Productivity	Oil Vulnerability	Systems Reliability	Health and Environmental Impacts	Greenhouse Gases	International Cooperation	Future Choices
Gap/Opportunity	I	II	III	IV	V	VI	VII
Advanced fuel and vehicle concepts	•	+		•			•
Advanced natural gas technologies	+	•		•	•		
Analysis tools for electricity markets	•		+				

Indoor environmental quality	•			+				
International R&D partnerships				•	•	+		
Land and water impacts				+				
Long-term greenhouse gas technologies					+	•	•	
Multi-attribute life-cycle analysis				+	•	•		
Non-petroleum energy supplies	•	+			•			
On-board hydrogen storage		•		•	+			
Real-time controls and measurement	•		+					

*A plus sign denotes primary relevance, a dot indicates major relevance, and no entry implies minor or no relevance to a given goal.

For expanding future choices (Goal VII), a priority set of gaps and opportunities is:

- coordinated longer term (i.e., 20- to 50-year) future visions for key energy areas;
- core-competency working groups for key science topics;
- international R&D collaborations in strategic longer term areas;
- systematic way to coordinate science activities and applied R&D; and
- technologies important to developing countries.

Systematic coordination of science activities and applied R&D, coordinated longer term future visions for key energy areas, and core-competency working groups for key science topics are the three most important gaps and opportunities directly associated with the Future Choices goal. These gaps and opportunities correspond more closely to portfolio planning opportunities than R&D investments and, as such, are omitted from the list of priority gaps and opportunities.

PORTFOLIO PLANNING OPPORTUNITIES AND NEEDS

Important planning opportunities and needs for improving the overall effectiveness of the R&D portfolio, many involving greater integration and coordination of related R&D efforts, are development of:

- an overarching energy R&D portfolio strategy addressing short-, mid-, and long-term time horizons;
- a long-term carbon and greenhouse gas management strategy, plan, and program evaluation metrics;
- comprehensive technology deployment strategies, both domestic and international;
- systematic planning mechanisms for linking science and applied R&D; and
- coordination plans for cross-cutting technologies and disciplines, including
  - biotechnology;
  - catalysts;
  - materials;
  - membranes;
  - sensors and controls; and
  - systems integration.

The overarching energy R&D portfolio strategy should embrace the International Clean Energy Initiative as well as contain a long-term clean fuels strategy including hydrogen. Both of these activities are part of new DOE initiatives. The technology deployment strategies should include identifying and creating niche market introduction opportunities through a thorough understanding and analysis of competitive markets, interactions between technology and customers, and international trade policies. These long-term strategies should also reflect an understanding of the potential impacts of future greenhouse gas control options, such as carbon taxes, emissions permits, and emissions trading, on market opportunities for advanced technologies.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) manages a large and diverse portfolio of research and development (R&D) activities to support improvements in energy systems through technological advances. This portfolio is described in detail in the document *DOE Research and Development Portfolio: Energy Resources* (February 2000). These R&D activities are logically organized along functional lines (i.e., from various sources and conversion of energy to various uses of energy).

To evaluate how well this portfolio contributes to national strategic goals, the Under Secretary of Energy convened two expert stakeholder panels, as well as a consensus panel, to assess the DOE Energy Resources R&D Portfolio for producing results consistent with achieving strategic goals. The analysis was conducted to: (i) assess the adequacy of the Energy Resources R&D Portfolio in addressing strategic goals and (ii) identify any gaps in the current R&D portfolio. In addition, the panels indicated R&D and planning opportunities that should be explored, as well as the relative importance of R&D programs to each strategic goal. The results of Panels I, II, and III are documented more extensively in three associated reports, respectively, *Energy Resources R&D Portfolio Analysis: Definition of Overarching Objective, Adequacy, Strategic Goals and Associated Issues, Technology Categories, and Program Elements* and *Energy Resources R&D Portfolio Analysis: Portfolio Adequacy in Addressing Strategic Goals*, and *Energy Resources R&D Portfolio Analysis: Summary of Findings*.

This analysis builds on the experience of a mid-1999 analysis of the Energy Resources R&D Portfolio by conducting a more robust analysis involving a more diverse set of energy R&D stakeholders. The results of the mid-1999 analysis are documented in a three-volume set of reports entitled, *Energy Resources R&D Portfolio Analysis.* The DOE Fiscal Year 2001 budget request includes a number of funding adjustments in response to these findings. Moreover, the portfolio has changed significantly in some areas since the mid-1999 analysis as a result of new Secretarial and/or Presidential initiatives, many of which address deficiencies observed by the mid-1999 portfolio analysis. The Energy Resources R&D Portfolio (February 2000) assumes these budget requests will be approved by Congress. This portfolio analysis is based on that same assumption.

The panels acknowledged the constructive changes made by DOE in the Energy Resources R&D Portfolio (February 2000). Many of these changes align well with the recommendations put forth by the mid-1999 portfolio analysis.

1.1 Structure of the Analysis

Panelists were selected from DOE, the DOE national laboratories, industry, universities, and nongovernmental organizations (Appendix A). A strategic planning methodology developed by Sandia National Laboratories, the Vital Issues Process, guided the panel meetings. Panel I convened on January 12-13, 2000, to refine and elaborate strategic goals and associated issues for use by Panel II in evaluating the portfolio. Panel I derived seven goals from the strategic goals contained in the *Comprehensive National Energy Strategy* (CNES) published by DOE in April 1998 and two reports prepared by the President's Committee of Advisors on Science and

Technology (PCAST), namely, *Federal Energy Research and Development for the Challenges of the Twenty-First Century* and *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation*, published in November 1997 and June 1999, respectively. These goals are as follows:

(I) Improve the economic efficiency of the energy supply and end-use systems to enhance overall performance of the U.S. economy (Economic Productivity).
(II) Reduce the vulnerability of the U.S. economy to disruptions in oil supply (Oil Vulnerability).
(III) Ensure energy systems reliability, flexibility, emergency response capability, and risk management (Systems Reliability).
(IV) Reduce health and environmental impacts (Health and Environmental Impacts).
(V) Stabilize greenhouse gas concentrations (Greenhouse Gases).
(VI) Cooperate internationally on global issues (International Cooperation).
(VII) Expand future energy choices (Future Choices).

Panel I provided the framework for the portfolio analysis work undertaken by Panel II, including derivation of an objective statement for the energy R&D portfolio to guide the portfolio analysis by Panel II as follows:

> Promote the development of energy systems and practices that increase energy options for improving overall economics, using resources more efficiently, and reducing adverse impacts of energy supply and use.

Panel I also determined that measures of adequacy of the portfolio should be guided by a key question as follows:

> Is the portfolio likely to produce results that are needed to make significant progress toward the strategic goals? If yes, the portfolio is adequate. If no, the portfolio is inadequate.

Finally, a set of vital issues associated with each goal was derived by Panel I. The issues were identified to provide additional definition to the goals to assist Panel II in measuring portfolio adequacy with respect to a given goal. Panel I also ranked the relative importance of each issue associated with each goal. The issues expressed as questions in the order of decreasing importance for each goal, along with their short titles given in parentheses, are as follows:

Economic Productivity (Goal I) - How well do the R&D activities seek to:

- Increase the efficiency and availability and achieve least cost, including externalities, of end-use services? (End Use)
- Improve the efficiency and availability and reduce the cost, including externalities, of primary and secondary energy supply systems? (Supply)

Oil Vulnerability (Goal II) - How well do the R&D activities seek to:

- Lower the dominance of petroleum in the transportation sector? (Dominance)

- Reduce the exposure of the U.S. economy to adverse effects of oil price shocks from supply disruptions? (Exposure)
- Increase the diversity and robustness of global oil supplies? (Diversity)

Systems Reliability (Goal III) - How well do the R&D activities seek to:
- Improve the electrical power system resiliency under deregulation and restructuring? (Electric Deregulation)
- Improve the natural gas system resiliency? (Gas Resiliency)
- Increase the resistance of energy supply and delivery systems to cyber or physical terrorism and natural disasters? (Terrorism)
- Mitigate any adverse consequences due to the increasing interdependence of the electric power and natural gas systems? (Interdependence)

Health and Environmental Impacts (Goal IV) - How well do the R&D activities seek to:
- Facilitate regulatory system compliance while reducing the cost of mitigation? (Regulations)
- Manage materials flows from the perspectives of life-cycle impacts and industrial ecology? (Materials Flows)
- Reduce nonregulated adverse health and environmental impacts? (Nonregulated Impacts)

Greenhouse Gases (Goal V) - How well do the R&D activities seek to:
- Improve energy efficiency of end-use and power production facilities? (Efficiency)
- Facilitate decarbonization of the energy mix? (Energy Mix)
- Support sequestration of fossil carbon, enhancement of natural carbon sinks, and deliberate removal of carbon dioxide and other greenhouse gases from the atmosphere? (Sequestration)
- Facilitate shifts in economic structure away from carbon consumption? (Economic Shifts)

International Cooperation (Goal VI) - How well do the R&D activities seek to:
- Address potential long-term energy sector sustainability issues including nuclear proliferation? (Sustainability)
- Form international working partnerships for energy technology planning and implementation? (Technology Partners)
- Establish international cooperative networks in energy R&D planning and information sharing? (R&D Networks)

Future Choices (Goal VII) - How well do the R&D activities seek to:
- Integrate new results from long-term successful science into near-term technology? (Science to Technology)
- Communicate technology needs to long-term science research? (Technology to Science)
- Develop long-term energy technology choices? (Long-Term Choices)

Panel I made no changes to the seven technologies categories of the Energy Resources R&D Portfolio as outlined in the *DOE Research and Development Portfolio: Energy Resources* (February 2000). To facilitate the work of Panel II, a few modifications were made by Panel I to

the program elements composing some of the technology categories. The Modified Energy Resources R&D Portfolio used by Panel II is illustrated in Figure 1. The final set of seven technology categories and 22 program elements are summarized as follows:

Enhancing Domestic Supplies

- oil and gas exploration and production
- oil and gas processing

Producing Clean Fuels

- coal-derived fuels
- natural gas-derived fuels
- petroleum-derived fuels
- fuels from biomass and wastes
- hydrogen production and systems

Advanced Power Systems

- large fossil systems, including advanced coal gasification and combustion systems, advanced gas turbine systems, and advanced large-scale fuel cell power systems
- distributed fossil systems, including combined heat and power systems, advanced turbine systems, distributed fuel cell power systems, and reciprocating engines
- carbon sequestration
- nuclear systems
- renewable systems, including wind energy systems, photovoltaic systems, concentrating solar power technology, geothermal systems, biopower, and hydropower

Enhancing Energy Systems Reliability

- electric power systems
- natural gas infrastructure
- secure energy infrastructure

Clean and Efficient Vehicles

- cars of the future, partnership for a new generation of vehicles (PNGV), and light trucks, including engine/power sources, systems development, advanced materials, and fuels utilization
- high-efficiency heavy trucks

Efficient and Affordable Buildings

- building equipment and appliances, including heating, ventilation, and air conditioning; lighting and appliances; and on-site generation
- building materials and envelopes
- building design, operation, and information systems

Clean and Productive Industries

- industries of the future, including aluminum, steel, metal casting, forest products, glass, chemical, mining, agriculture, and petroleum refining; and

- crosscutting technologies, including enabling technologies, technical assistance, and financial assistance

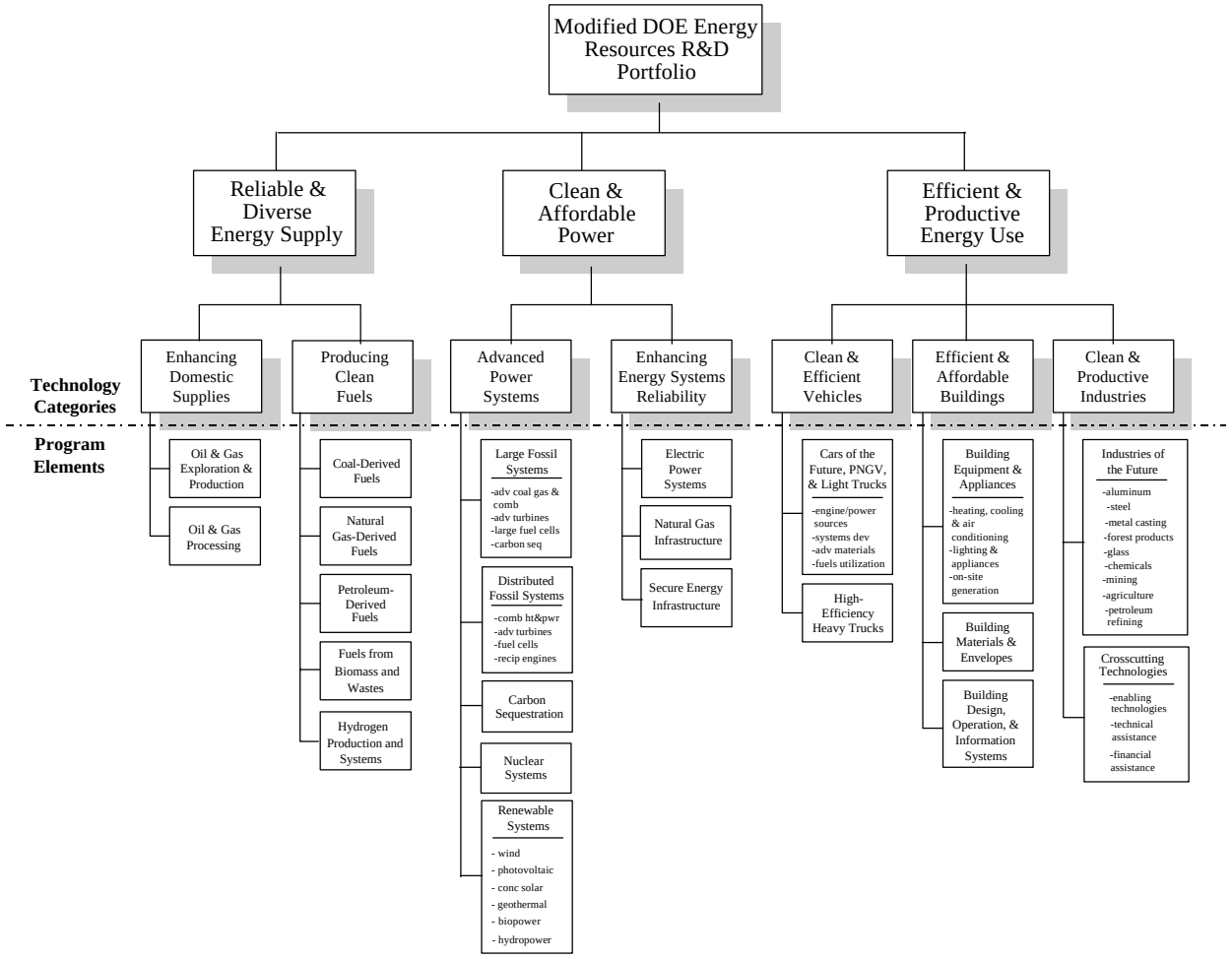

Fig. 1. Modified Energy Resources R&D Portfolio Derived by Panel I.

Panel II convened on February 22-25, 2000. To assist Panel II in its deliberations, R&D managers selected by DOE summarized the roles of the technology categories and program elements in achieving each of the seven goals. In addition to describing the R&D activities contained within the respective technology categories and program elements, as defined by Panel I, each presenter was asked specifically to address the projected results of the R&D activities for contributions to the goals and to identify gaps and opportunities within the technology categories or program elements.

The first two days of Panel II were devoted to reviewing the program elements and their overarching technology categories for contributions to each of the seven goals. This review led to a pairwise comparison of the relative importance of each program element and each technology

category for each goal. With this review as background, the final two days of Panel II were devoted to addressing the two principal purposes of the portfolio analysis:

- assessment of the adequacy of the Energy Resources R&D Portfolio in addressing the goals; and
- identification of any gaps in the current R&D portfolio for achieving the goals.

Panel III convened on May 24 and 25, 2000, to refine the results of the analysis performed by Panel II and to prepare a summary presentation to the members of the R&D Council responsible for energy R&D programs. This presentation was made on May 25, 2000, and is attached as Appendix B.

1.2 Organization of the Report

The remainder of the report is organized to focus on the primary objectives of the analysis. Section 2.0 summarizes the judgment of Panel II related to the adequacy of the energy R&D portfolio in addressing the goals. Discussions of gaps in the portfolio and R&D opportunities are also included for each goal. Section 3.0 identifies priority gaps and opportunities within the current portfolio. Portfolio planning opportunities and needs are summarized in Section 4.0. A condensation of the most important findings of the analysis is given in Section 5.0.

2.0 PORTFOLIO ADEQUACY IN ACHIEVING GOALS

The principal objective of the portfolio analysis was to assess the adequacy of the DOE Energy Resources R&D Portfolio for making significant progress toward achieving important national goals. The assessment by Panel II of adequacy for each goal was done subjectively after the panelists had heard descriptions of, and discussed extensively, the technology categories and program elements in the Energy Resources R&D Portfolio.

No explicit assessment was made of the adequacy of the budget for any program element or technology category. In fact, budget considerations were exempted from the presentations and generally from the discussions. Adequacy in the context of this analysis, therefore, does not imply budget sufficiency. Identification of important portfolio R&D gaps and opportunities often indicates budget insufficiencies or, perhaps, budget misallocations. Furthermore, a judgment of less than adequate in addressing a goal does not imply any evaluation of the quality of the R&D being performed in the portfolio. In the context of this analysis, a goal could be judged to be addressed inadequately even though the R&D activities are of the highest quality.

An important dimension to assessments of adequacy is related to the need for R&D investments by the Federal government. For some goals, the private-sector investment in relevant energy R&D may be more significant than that of the Federal government. For others, the Federal government must take a leadership role, but strong participation by industry, academia, nongovernmental organizations, and Federal policy makers will be important to setting a cost-effective course for action. For this reason, each DOE presenter was asked to explain the need for a Federal government role in his or her R&D area. Clearly, national goals are not necessarily the primary goals of the private sector; but, if the accomplishments of energy R&D are to reach commercial

markets effectively, the private sector must be involved. Often public-private partnerships are the most productive means for carrying out the R&D. For this reason, each DOE presenter was also asked to identify important R&D partnerships with industry. These dimensions represent additional complicating factors Panel II attempted to consider in assessing the adequacy of the R&D portfolio.

Each panel member rated the adequacy of the portfolio in addressing each of the issues associated with the seven goals. The frequency of the panelists selecting a summary evaluation of high, medium, low, or not at all with respect to the degree to which the R&D activities comprising the Energy Resources R&D Portfolio seek to resolve the issues associated with each of the strategic goals was combined with a numerical scoring scale (i.e., high = 3, medium = 2, low = 1, not at all = 0) to compute issue adequacy values (Table 1).

Table 1. Adequacy of the Entire Energy Resources R&D Portfolio in Addressing the Issues Associated with the Seven Goals.

Goal	Issue Adequacy Index*	Relative Importance
Economic Productivity		
End Use	2.25	0.59
Supply	2.13	0.41
Oil Vulnerability		
Dominance	2.22	0.36
Exposure	2.11	0.35
Diversity	1.89	0.29
Systems Reliability		
Electric Deregulation	2.06	0.30
Gas Resiliency	1.82	0.24
Terrorism	1.88	0.24
Interdependence	1.65	0.22
Health and Environmental Impacts		
Regulations	2.78	0.37
Materials Flows	1.39	0.37
Nonregulated Impacts	1.22	0.26
Greenhouse Gases		
Efficiency	2.56	0.29
Energy Mix	1.89	0.28
Sequestration	2.06	0.24
Economic Shifts	0.72	0.19
International Cooperation		
Sustainability	1.47	0.44
Technology Partners	1.29	0.30
R&D Networks	1.89	0.26
Future Choices		
Science to Technology	1.56	0.36

Technology to Science	1.61	0.34
Long-Term Choices	2.17	0.30

*Although the values are reported in two significant digits, this level of accuracy is an arithmetic artifact because the scoring scale used to generate these results was an integer scale ranging from zero to three.

The relative importance of each issue for a given goal as determined by Panel I is also included in Table 1. A relatively high or low adequacy rating is not necessarily correlated with a high or low relative importance for that issue. For example, some inadequately addressed issues (i.e., those with relatively low ratings) were judged by Panel I to be relatively important, whereas others were not.

Based on these results, four of the subordinate issues are particularly well addressed. Thus, the Energy Resources R&D Portfolio is well positioned to:

- facilitate regulatory system compliance while reducing the cost of mitigation (Regulations);
- improve energy efficiency of end-use and power production facilities (Efficiency);
- increase the efficiency and availability and achieve least cost, including externalities, of end-use services (End Use); and
- lower the dominance of petroleum in the transportation sector (Dominance).

The Energy Resources R&D Portfolio does not seek particularly well to:

- facilitate shifts in economic structure away from carbon combustion (Economic Shifts);
- reduce nonregulated adverse health and environmental impacts (Nonregulated Impacts); or
- form international working partnerships for energy technology planning and implementation (Technology Partners).

Moreover, improvements in the Energy Resources R&D Portfolio are warranted in efforts to:

- manage materials flows from the perspectives of life-cycle impacts and industrial ecology (Materials Flows);
- address potential long-term energy sector sustainability issues including nuclear proliferation (Sustainability);
- integrate new results from long-term successful science into near-term technology (Science to Technology);
- communicate technology needs to long-term science research (Technology to Science); and
- mitigate any adverse consequences of the increasing interdependence of the electric power and natural gas systems (Interdependence).

The results of the adequacy assessments at the issue level can be combined using the relative weights of the issues associated with each strategic goal determined by Panel I to compute a composite adequacy index for each goal (Table 2).

Table 2. Adequacy of the Entire Energy Resources R&D Portfolio in Addressing the Seven Goals.

Goal	Composite Adequacy Index*
Economic Productivity	2.20
Oil Vulnerability	2.09
Systems Reliability	1.87
Health and Environmental Impacts	1.86
Greenhouse Gases	1.91
International Cooperation	1.53
Future Choices	1.76

*Although the values are reported in two significant digits, this level of accuracy is an arithmetic artifact because the scoring scale used to generate these results was an integer scale ranging from zero to three.

Economic Productivity (Goal I) and International Cooperation (Goal VI) represent the high and low values, respectively, of the adequacy index as a measure of the overall portfolio adequacy in addressing the seven strategic goals. The most strongly addressed goals are Economic Productivity (Goal I) and Oil Vulnerability (Goal II). Relatively small differences in ratings are present for Greenhouse Gases (Goal V), Systems Reliability (Goal III), and Health and Environmental Impacts (Goal IV). The least strongly addressed goals are International Cooperation (Goal VI) and Future Choices (Goal VII). However, some of the subordinate issues associated with Goals III through VII have substantially different measures of adequacy.

Based on these results, as well as the Panel II discussions (Sections 2.1 through 2.7), two of the seven goals, namely, Economic Productivity (Goal I) and Oil Vulnerability (Goal II) are judged to be addressed adequately by the Energy Resources R&D Portfolio. These two goals received relatively high adequacy ratings for the most important issues as well as reasonably high ratings for all of the subordinate issues. Substantial opportunities for improving the adequacy of the Energy Resources R&D Portfolio with respect to International Cooperation (Goal VI) and Future Choices (Goal VII) are present. As such, Goals VI and VII are judged to be addressed inadequately.

Systems Reliability (Goal III), Health and Environmental Impacts (Goal IV), and Greenhouse Gases (Goal V) are judged to be addressed in a conditionally adequate manner. For these goals, a judgment of conditional adequacy reflects substantial differences in the issue adequacy index for the subordinate issues, especially with one or more issues receiving a particularly low adequacy rating; the presence of new R&D efforts without substantive results; or relatively strong disagreements on portfolio adequacy among the panelists.

The composite adequacy index for each of the seven goals (Table 2) can be combined with measures of the relative contributions of the technology categories to each goal to generate a visual representation (Figure 2) of the adequacy of the entire Energy Resources R&D Portfolio in addressing the goals. Figure 2 reflects two important but quite different results for each goal: (i) the overall adequacy of the portfolio indicated by the average of the bar heights and (ii) the relative contributions of technology categories as reflected by the differences between the bar heights and the average. This dual representation provides a convenient visual depiction of two important results of the analysis.

The following seven subsections summarize the Panel II discussions related to the adequacy of the entire Energy Resources R&D Portfolio for each of the seven goals. These summaries are intended to provide an additional perspective with respect to the adequacy of the R&D portfolio, but may not in every case be entirely consistent with the adequacy determinations based on the numerical ratings (Section 2.0). Moreover, these discussions do not necessarily reflect a consensus of the members of Panel II and may include items related to goals other than the one specified. Gaps in the current R&D portfolio as well as new R&D investment opportunities suggested during the Panel II discussions are also presented. The lists of gaps and opportunities for each goal are derived from the discussions occurring for that goal. In some cases, included items may address one or more other goals more strongly. Because Panel II did not have sufficient time to refine these gaps and opportunities as a coherent set, these lists need to be carefully analyzed by DOE. The highest priority gaps and opportunities are discussed in Section 3.0. More detail on the Panel II discussions is contained in the report, *Energy Resources R&D Portfolio Analysis: Portfolio Adequacy in Addressing Strategic Goals.*

2.1 Economic Productivity (Goal I)

2.1.1 *Adequacy*. The portfolio reflects a solid and adequate approach toward achieving improvements in economic efficiency of the energy supply and end-use systems to enhance the overall performance of the U.S. economy (Goal I). From the end-use perspective, even though the R&D portfolio was judged to adequately address Goal I, the portfolio performance could be improved by larger market penetration of advanced vehicles, better balance between the industry focus on short-term technologies and a longer term vision, attention to larger rather than simply incremental technical advancements in the PNGV program, a more holistic approach to buildings R&D, accelerated technology deployment efforts in buildings to help offset the slow inventory turn over, and more innovative thinking in collaborative R&D activities with industry. The portfolio could be enhanced from the energy-supply perspective by achieving greater balance between the emphasis on fossil-derived fuels and alternative fuels like biomass and hydrogen, devoting more attention to environmental considerations other than those emphasized by the current regulatory environment, ensuring that a focus on extending the life of existing power plants does not create a bias against or delays in deployment of new technologies, dedicating more intensive effort to carbon management, and giving more attention to externalities affecting the cost of energy supplies.

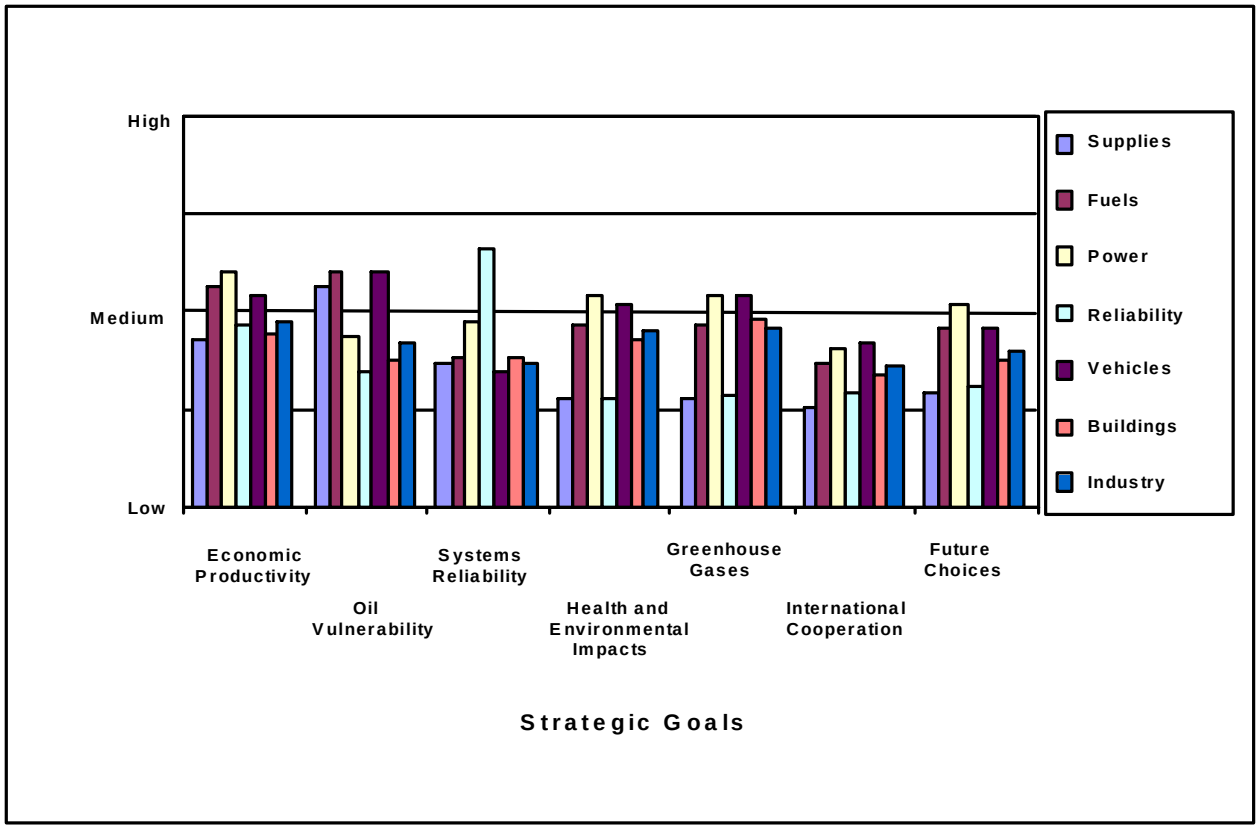

Fig. 2. Adequacy of the Entire Energy Resources R&D Portfolio in Addressing the Goals. The average height of the seven bars is equal to the overall adequacy of the portfolio for each goal. This average height corresponds directly to the composite adequacy index. The relative significance (or contribution) of the seven technology categories to each goal is indicated by the height of the individual bars. The difference between the height of a bar and the average is a measure of the relative contribution of a technology category in addressing a given goal. This relative contribution is derived from the pairwise comparisons made by Panel II as described in Section 5.1. The following abbreviations for technology categories are used: Enhancing Domestic Supplies, Supplies; Producing Clean Fuels, Fuels; Advanced Power Systems, Power; Enhancing Energy Systems Reliability, Reliability; Clean and Efficient Vehicles, Vehicles; Efficient and Affordable Buildings, Buildings; Clean and Productive Industries, Industry.

2.1.2 *Subordinate Issues*. The subordinate issues associated with Economic Productivity (Goal I) are addressed well by the portfolio (Table 1). The results of the R&D contained in the portfolio should contribute strongly to increasing the efficiency and availability and achieving least cost, including externalities, of end-use services (End Use). Similarly, the portfolio appears to be well positioned to improve the efficiency and availability and reduce the cost, including externalities, of primary and secondary energy supply systems (Supply).

2.1.3 *Gaps/Opportunities*. Possible gaps and/or opportunities in the portfolio include R&D related to access to remote natural gas resources; advanced technologies to meet expected natural gas demand increases (i.e., from 22 to 32 trillion cubic feet/year by 2020); consequences of carbon emissions; hybrid systems for stationary and mobile power sources; innovative technology

commercialization strategies; life-cycle cost analyses; methane hydrates; non-petroleum energy supply options; oil-price-sensitive demand sectors; power quality; smart buildings; and two- and three-wheeled vehicles.

The difference between carbon sequestration and managing the consequences of increased atmospheric concentrations of greenhouse gases, the vulnerability of some sectors of the economy (e.g., residential oil heating and heavy diesel trucks) to oil price shocks even though the U.S. economy is much more robust and resilient to oil price changes than in the 1970s, and a proper role for DOE in economic productivity without encroaching on domains more effectively addressed by the private sector represent important challenges. Road mapping, scenario building, or visioning exercises for the entire Energy Resources R&D Portfolio by goal would be a worthwhile activity, albeit a difficult and time consuming one.

2.2 Oil Vulnerability (Goal II)

2.2.1 *Adequacy*. Reducing the vulnerability of the U.S. economy to disruptions in oil supply (Goal II) is addressed adequately by the portfolio. Although the current U.S. economy is less susceptible to oil price shocks than during the 1970s and 1980s, the same vulnerability remains, that is, the transportation sector is almost totally dependent on oil and relative small decreases in supply can cause large price increases as was demonstrated in late 1999 and early 2000. Specific sectors, such as heavy trucks and residential heating in the Northeastern U.S., are particularly sensitive to oil price shocks. This vulnerability is long term and its mitigation will be partially dependent on advanced supply and end-use technologies; but the most influential leverage for reducing exposure to oil price shocks may not be R&D related at least in the short term.

Strong differences of opinion exist with regard to an appropriate Federal government role in supporting R&D for expanding domestic fossil fuel energy supplies as a means to reduce oil vulnerability. Because oil is a highly traded international commodity, the geographical location of the supply can be argued as being insignificant. From this perspective, many of the policy rationales for supporting enhanced domestic oil production are unconvincing. On the other hand, oil and gas exploration and production R&D within the Enhancing Domestic Supplies technology category can serve to enhance production in other nations.

2.2.2 *Subordinate Issues*. The portfolio addresses the three subordinate issues associated with Oil Vulnerability (Goal II) well (Table 1). With respect to the dominance of petroleum in the transportation sector (Dominance) and exposure of the U.S. economy to adverse effects of oil price shocks from supply disruptions (Exposure), R&D contributions are being made by the development of fuel substitutes via the Producing Clean Fuels technology category and through fuel efficiency improvements sought by the Clean and Efficient Vehicles technology category. Notwithstanding the debate regarding a proper Federal government role, the R&D in the Enhancing Domestic Supplies technology category should help increase the diversity and robustness of global oil supplies (Diversity).

2.2.3 *Gaps/Opportunities*. Advanced concepts for fuels and vehicles; bioengineering and genomics related to biofuels; exploration and production technology for increasing domestic oil

and gas supplies focused toward independent producers; fuel cells for heavy trucks; high-efficiency sport utility vehicles; international cooperation on vehicle technology; mass transportation; membranes and Fischer-Tropsch catalysts for conversion of gases to liquids; methane hydrates; on-board hydrogen storage systems; the Scientific Simulation Initiative; and western hemisphere natural gas and oil resources represent gaps and/or opportunities in the current portfolio.

Technology deployment strategies for clean fuels, as well as many other components of the portfolio, are insufficiently delineated. Meeting worldwide future fuel needs represents an extraordinary technical challenge. The depletion of easily accessible oil and gas resources makes the U.S. an attractive testbed for advanced exploration and production technologies. Applications of fuel cells to heavy trucks and city cycle driving, as well as the tradeoffs of using fuel cells with on-board reforming and advanced diesel engines, are important topics for consideration. The appropriateness of a focused vehicle development program, like PNGV, should be evaluated for advanced sport utility vehicles.

2.3 Systems Reliability (Goal III)

2.3.1 *Adequacy*. Due to the strong response to the gaps identified by the mid-1999 portfolio analysis, the current R&D portfolio has made significant advances with regard to adequately addressing energy systems reliability, flexibility, emergency response capability, and risk management (Goal III). Regardless, the Systems Reliability goal is judged to be addressed in a conditionally adequate manner, in large part, because many of the R&D activities are new and are yet to produce measurable results.

2.3.2 *Subordinate Issues*. Three of the four subordinate issues to improve the electrical power system resiliency under deregulation and restructuring (Electric Deregulation), to improve the natural gas system resiliency (Gas Resiliency), and to increase the resistance of energy supply and delivery systems to cyber or physical terrorism (Terrorism) are reasonably well addressed by the portfolio (Table 1). Further improvements to the overall adequacy in addressing Goal III could be achieved by more emphasis on R&D targeted toward mitigating any adverse consequences of the increasing interdependence of the electric power and natural gas systems (Interdependence).

2.3.3 *Gaps/Opportunities*. Possible gaps or opportunities in the current portfolio include R&D related to analysis tools and models applicable to deregulated electricity markets; distributed power surveys and analyses; high-temperature superconducting materials and devices; hydrogen infrastructure; leveraging energy grid models for other analyses; low-cost cryogenic systems; natural gas transmission and distribution system safety; natural gas transmission system models; power quality and storage; real-time control and measurement, including intelligent power electronics, local demand management, and smart meters; remote methane sensing technology for fugitive emissions; and state and local cooperation on policy and regulatory matters. Development of a carbon infrastructure, especially if carbon dioxide (CO_2) is to be transported prior to sequestration; the large relative contribution to the effects of atmospheric greenhouse gas concentrations by methane (i.e., ~ 20 times larger impact than CO_2); peak load management and

accurate control of the electric grid; and management of diurnal and seasonal electric load profiles at a building cluster level are topics worthy of consideration.

Although opportunities appear to exist for a more ambitious Federal government role in assisting the natural gas industry in improving the resiliency of the natural gas infrastructure through technology advancements, opinions on an appropriate Federal government role are mixed. Cited R&D opportunities include intra-hour metering necessary to respond to increased demands in a deregulated market, infrastructure aging, advanced materials for distribution systems, and models capable of sophisticated system design or siting of natural gas storage facilities. On the other hand, the natural gas industry has adapted well to a deregulated market and public support for R&D may be inappropriate for issues created by industry growth and change. Nonetheless, an expanded Federal government role in natural gas infrastructure may become increasingly important as deregulation eventually eliminates industry-wide R&D support through the Gas Research Institute.

2.4 Health and Environmental Impacts (Goal IV)

2.4.1 *Adequacy*. Reducing health and environmental impacts (Goal IV) is addressed in a conditionally adequate manner by the portfolio. Most of the R&D related to Goal IV is focused on near-term challenges of meeting increasingly strict environmental regulations. As such, facilitating regulatory compliance while reducing the cost of mitigation is addressed extremely well. Relatively little attention is devoted to land and water impacts compared to the efforts directed toward air-quality considerations. Extensive R&D cooperation with industry which orients much of the R&D toward near-term challenges, such as meeting increasingly strict air-quality regulations, is a strong driver of the current focus on regulatory matters. Some observers consider this situation as subsidizing industry efforts to meet environmental regulations. Others argue that this R&D is important to enabling compliance within the short timetables associated with rapidly evolving regulations, thereby extending the life of existing energy systems. If health and environmental impacts are viewed as important as energy efficiency considerations, then the portfolio is, perhaps, somewhat out of balance with respect to the relative levels of the R&D efforts on efficiency and environment. Nonetheless, there are substantial indirect environmental benefits from energy efficiency improvements and from the development of fuels and energy systems with inherently lower environmental impacts.

2.4.2 *Subordinate Issues*. Although the R&D activities in the current portfolio do extremely well in seeking to facilitate regulatory systems compliance while reducing the cost of mitigation (Regulations), substantial improvements are possible in managing materials flows from the perspectives of life-cycle impacts and industrial ecology (Materials Flows) and in reducing nonregulated adverse health and environmental impacts (Nonregulated Impacts). In fact, Regulations is most adequately addressed of the 22 issues associated with the strategic goals and is the most important of three subordinate issues associated with Goal IV. Managing materials flows is judged to be relatively important to achieving Goal IV, while reducing nonregulated adverse health and environmental impacts is the least important issue associated with Goal IV (Table 1).

2.4.3 *Gaps/Opportunities*. Environmental monitoring; improved technical and environmental performance of existing power plants; indoor environmental quality, including topics such as moisture levels, lighting, and human productivity; land and water impacts, particularly treated systematically rather than merely from a remediation perspective; land impacts (i.e., right-of-way requirements) resulting from expansion of the natural gas transmission and distribution infrastructure; multi-attribute life-cycle analysis; and nuclear power represent gaps and/or opportunities in the current portfolio. In addition, developing a strong technical basis for possible regulations addressing currently nonregulated impacts is an opportunity.

Understanding, analyzing, and possibly influencing the international regulatory environment is an important opportunity. Opportunities also appear to be present for scientific collaborations with either the DOE Office of Basic Energy Research or the National Institutes of Health on long-term environmental- and health-related research. Expanding and refocusing the R&D efforts on nuclear power to include topics such as materials flows, waste management, and advanced separation techniques is worthy of consideration as is considering possible long-term environmental impacts of technologies normally characterized as being environmentally friendly.

2.5 Greenhouse Gases (Goal V)

2.5.1 *Adequacy*. The current portfolio addresses stabilizing greenhouse gas concentrations (Goal V) in a conditionally adequate manner. Much of the R&D is quite applied and, generally, short-term in focus. Specifically, the shorter term topics, such as energy efficiency, are better addressed than the longer term challenges of carbon sequestration, decarbonization of the energy mix, and lowering the carbon intensity of the economy. Carbon sequestration is being addressed but largely in isolation from other energy system developments. From a long-term perspective, the level of effort on carbon sequestration may not be well matched with the magnitude of the technical challenges. In fact, climate change attributed to the build up of greenhouse gases in the atmosphere may well be the most significant threat to the supply of affordable U.S. energy supplies during the next several decades.

Greenhouse gases is the most recent goal to be addressed by the R&D portfolio, which may account for the some imbalance in short-term and long-term R&D efforts. Although some work has been ongoing for many years in the Office of Fossil Energy, widespread serious attention to greenhouse gases R&D in the Office of Fossil Energy has only been present in the portfolio in recent years. In the past, the principal energy R&D challenges were increasing supplies and reducing demand through efficiency improvements. At present, the greatest challenge may be combusting energy resources in an environmentally acceptable manner, particularly fossil energy supplies requiring carbon management. Coordination between technology and policy issues related to greenhouse gases is extremely important. International collaborations on carbon management have aspects distinct from a domestic strategy. Integrated R&D efforts with time scales well beyond the Kyoto Protocol (i.e., 2008 to 2012) are needed.

2.5.2 *Subordinate Issues*. The shorter term issue of improving energy efficiency of end-use and power production facilities (Efficiency) is addressed very well (Table 1). The R&D supporting sequestration of fossil carbon, enhancement of natural carbon sinks, and deliberate removal of

CO_2 and other greenhouse gases from the atmosphere (Sequestration) is reasonably adequate as is that addressing decarbonization of the energy mix (Energy Mix). Although facilitating shifts in economic structure away from carbon consumption (Economic Shifts) is by far the least adequately addressed issue among the 22 issues associated with the seven goals, this issue is judged to be relatively low in importance to achieving Goal V (Table 1).

2.5.3 *Gaps/Opportunities*. Potential gaps or opportunities in the current portfolio are R&D related to adaptation to rising atmospheric carbon concentrations; advanced chemistry and biology (e.g., related to biofuels or the natural carbon cycle); advanced nuclear power including waste treatment and materials; greenhouse gases other than CO_2; integrated advanced power and CO_2 separation systems; integrated carbon management models including economic considerations; internationalization of carbon management R&D; a long-term clean fuels strategy including hydrogen; a long-term greenhouse gas goal, strategy, and program evaluation metrics; and terrestrial near- to mid-term technologies to support global climate treaty negotiations.

An integrated view of carbon sequestration including fungible measures such as economics, emissions rates, atmospheric concentrations, and spatial considerations; land-based sources (e.g., wetlands, tundra, and landfills) of greenhouse gases; fugitive methane emissions and methane hydrate contributions to greenhouse gas concentrations; and inclusion of other gases (e.g., nitrous oxide and halocarbons) in a comprehensive greenhouse gas strategy are important topics for consideration. Since carbon management is given little attention in many parts of the portfolio, a holistic carbon management strategy could be developed and used to influence the focus of R&D efforts.

2.6 International Cooperation (Goal VI)

2.6.1 *Adequacy*. International cooperation on global issues (Goal VI) is the least adequately addressed goal by the current portfolio. The contributions to Goal VI are inadequate but improving. However, efforts in international cooperation are heavily dominated by attendance at technical meetings and conferences and sharing information. Very little true collaborative R&D is contained within the portfolio. A lack of definitive programmatic goals on international cooperation and partnership in R&D planning, implementation, and information sharing is apparent. Establishing formalized technology partnership agreements for the scoping, planning, research, and development of specific technologies from which mutual benefit can be derived could improve the performance of the portfolio. Institutionalizing the International Clean Energy Initiative within the R&D portfolio and creating a comprehensive and integrated road map of R&D, including technology deployment strategies and metrics, throughout the relevant parts of the portfolio would make important contributions toward achieving Goal VI.

In response to the 1999 report by the President's Committee of Advisors on Science and Technology, *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation*, a multi-agency task force was established and a new initiative, the International Clean Energy Initiative, was proposed in the Fiscal Year 2001 budget request. The DOE portion of this initiative, if approved by Congress, should reduce significantly many of the deficiencies in the portfolio related to cooperating internationally on global issues. Specific high-priority actions

identified by Panel II that could improve the adequacy of the Energy Resources R&D Portfolio related to the International Cooperation goal are expanding international technology partnerships and cooperative R&D and implementing economic development or aid agreements with developing countries involving deployment of clean and efficient energy technologies.

2.6.2 *Subordinate Issues*. Although the portfolio addresses the establishment of international cooperative networks in energy R&D planning and information sharing (R&D Networks) reasonably well (Table 1), this issue is the least important of the three subordinate issues associated with Goal VI. Improvements in the portfolio could be realized through expanding cooperative R&D networks, particularly with developing countries, to plan and conduct joint research and share information on clean and energy efficient energy technologies. The most important issue of addressing potential long-term energy sector sustainability issues including nuclear proliferation (Sustainability) is relatively poorly addressed. More work directed toward addressing long-term energy sector sustainability issues, including nuclear proliferation, could enhance significantly international cooperation on global issues. Similarly, forming international working partnerships for energy technology planning and implementation is not well addressed by the portfolio (Technology Partners). This issue is the third worst addressed subordinate issue among the 22 issues associated with the strategic goals.

2.6.3 *Gaps/Opportunities*. Collaborative R&D with industry in developing countries on clean and efficient energy technologies; cost-shared international R&D collaborations with U.S. industry; economic development or aid agreements with developing countries involving deployment of clean and efficient energy technologies; international technology partnerships and cooperative R&D; internships with developing country research organizations on clean and efficient energy technologies; linkages with national academies in foreign countries; reconciliation of U.S. export promotion and international cooperation objectives; and support of the International Clean Energy Initiative represent important gaps and/or opportunities in the current portfolio.

Possibilities for improved international collaboration include capitalizing on offshore deployment strategies for advanced vehicles where high fuel prices serve as a market penetration motivator, the strong interest in international collaboration on nuclear R&D, the International Clean Energy Initiative as an impetus to move forward with other cooperative R&D activities, export opportunities for U.S. energy technologies, and the international connections of the National Academy of Sciences and the National Research Council to facilitate the formation of functional R&D agreements with their counterparts in foreign countries.

More specific examples of opportunities for expanding technology partnerships and cooperative R&D include methane hydrate research with Japan, advanced gas recovery and deep well recovery technologies for applications in the Gulf of Mexico with Mexico, Arctic oil and gas recovery technology with Canada and Russia, proliferation resistant nuclear reactor and fuel concepts with Russia, and advanced vehicles with developing countries projected to rapidly increase the use of motorized transportation. In general, cooperative R&D could be sought on crosscutting technologies (e.g., sensors and controls, combustion, intelligent power electronics, and advanced materials) and in areas that are gaps in the R&D portfolio. Foreign cost-shared

R&D with U.S. industry could be sought, for example, for the Superconductivity Partnership Initiative and the Energy Efficiency Science Initiative. China, India, and Mexico are examples of countries with which economic development agreements, including indigenous manufacturing, might be established to help implement clean vehicle and energy efficient appliance technologies.

2.7 Future Choices (Goal VII)

2.7.1 *Adequacy*. The portfolio addresses expanding future energy choices (Goal VII) in an inadequate manner. Well-defined short-term R&D needs are much better addressed than R&D activities with longer-term perspectives and time horizons. At present, the success of integrating new results from long-term science into near-term technology is variable and not systematic across the portfolio. Positive results are heavily dependent on individual program managers. The communication of technology needs to long-term science research is also variable throughout the portfolio, but is facilitated when applied programs develop science initiatives with the Office of Science.

2.7.2 *Subordinate Issues*. Although developing long-term energy technology choices (Long-Term Choices) is addressed relatively well (Table 1), this issue is the least important of the three subordinate issues associated with Goal VII. Efforts to integrate new results from long-term successful science into near term technology (Science to Technology) and to communicate technology needs to long-term science research (Technology to Science) could be improved substantially. These latter two issues are relatively poorly addressed. In addition to the lack of integration of the applied R&D program offices and the basic research in the Office of Science, the R&D contained in the current portfolio is overly focused on near-term technologies and lacks the required substance related to longer term technologies.

2.7.3 *Gaps/Opportunities*. Gaps and/or opportunities in the current portfolio include coordinated longer term (i.e., 20- to 50-year) future visions for key energy areas; core-competency working groups for key science topics; delineation of a Pasteur-quadrant science agenda; R&D collaborations with the international community in strategic longer term areas; R&D on long-term enabling technologies; the short-term focus of applied R&D widening the distance from science programs; a systematic way to coordinate and extend longer term visions; a systematic way to tie science activities to applied R&D; and technologies important to developing countries. The highest priority gaps and opportunities are coordinated longer term future visions for key energy areas; core-competency working groups for key science topics; R&D collaborations with the international community in strategic longer term areas; a systematic way to tie science activities to applied R&D; and technologies important to developing countries. Several of these priority gaps and opportunities do not represent R&D investments and, as such, are addressed in the context of portfolio planning opportunities and needs (Section 4.0).

The presence of some long-term visions is evident in the portfolio, but research on enabling technologies is limited. Key technology areas in need of long-term future visions are, for example, transportation systems, clean fuels, power generation, infrastructure, greenhouse gas management, and buildings. Important science topics are methane hydrates, advanced materials, energy storage, biotechnology and bioengineering, information technology and systems

management, and superconductivity. The applied R&D in the portfolio could identify future (i.e., five plus years) research results as a way to initiate targeted research programs with corresponding time horizons with the Office of Science. International R&D collaborations on long-term topics could include relationships with the National Science Foundation. Examples of important enabling technologies are hydrogen storage, carbon sequestration, advanced post-PNGV vehicles, and smart buildings.

Development of an overall long-term strategy for the Energy Resources R&D Portfolio using appropriate methodologies, such as R&D road maps, visioning exercises, and scenario generation and analysis, is an important activity for consideration. Technology deployment strategies should be a component of such a strategy because successful R&D needs to be coupled effectively with policy, regulatory, and economic considerations to achieve national energy-related goals.

3.0 PRIORITY GAPS AND OPPORTUNITIES

Panel II identified priority gaps and opportunities for each of the seven goals, except Goal VII. For the Future Choices goal, Panel II adopted a comprehensive list of gaps or opportunities as a coherent and integrated set without assigning priorities. Panel III narrowed this comprehensive list by identifying the three highest priority gaps and opportunities. Thus, the three highest priority gaps and opportunities, as refined by Panel III and listed in declining order, for the seven strategic goals are as follows:

Economic Productivity (Goal I)

- non-petroleum energy supply options
- advanced technologies to meet expected natural gas demand increases
- methane hydrates

Oil Vulnerability (Goal II)

- western hemisphere natural gas and oil resources
- on-board hydrogen storage systems
- advanced concepts for fuels and vehicles

Systems Reliability (Goal III)

- real-time control and measurement, including intelligent power electronics, local demand management, and smart meters
- analysis tools and models applicable to deregulated electricity markets
- natural gas transmission system models (tie)
- power quality and storage (tie)

Health and Environmental Impacts (Goal IV)

- indoor environmental quality, including air quality, air exchange and moisture level, artificial and natural lighting, and human productivity considerations (tie)
- multi-attribute life-cycle analysis, including health and environmental considerations (tie)
- land and water impacts of materials flows

Greenhouse Gases (Goal V)

- long-term greenhouse gas goal, strategy, and program evaluation metrics
- long-term clean fuels strategy including hydrogen
- advanced nuclear power including waste treatment and materials

International Cooperation (Goal VI)

- international technology partnerships and cooperative R&D
- support of the International Clean Energy Initiative
- deployment of clean and efficient energy technologies to developing countries

Future Choices (Goal VII)

- systematic way to coordinate science activities and applied R&D
- coordinated longer term (i.e., 20- to 50-year) future visions for key energy areas
- core-competency working groups for key science topics.

Based on these results as well as the discussions and deliberations on the program elements, technology categories, and portfolio adequacy, Panels II and III generated an overall list of the most important gaps and opportunities corresponding to possible R&D investments. Many of these topics are addressed by the current Energy Resources R&D Portfolio, but inadequately; while others are essentially absent. In the first instance, the topics may be considered as opportunities for expanded R&D efforts. In the latter case, the topics may represent true gaps in the R&D portfolio. A short list of these topics, without making a distinction between gaps and opportunities and excluding those for the Future Choices goal, includes (in alphabetical order):

- advanced concepts for fuels and vehicles (i.e., post Partnership for a New Generation of Vehicles);
- advanced technologies to meet expected natural gas demand increases (e.g., emphasis on western hemisphere resources and methane hydrates);
- analysis tools and models applicable to deregulated electricity markets;
- indoor environmental quality, including air quality, air exchange and moisture level, artificial and natural lighting, and human productivity considerations;
- international technology partnerships and cooperative R&D;
- land and water impacts of materials flows;
- long-term greenhouse gas stabilization technologies;
- multi-attribute life-cycle analysis, including health and environmental considerations;
- non-petroleum energy supply options;
- on-board hydrogen storage systems; and
- real-time control and measurement, including intelligent power electronics, local demand management, and smart meters.

These gaps and opportunities address a variety of the strategic goals. Each gap or opportunity is assigned primary relevance to a specific goal. In addition, these gaps and opportunities have major relevance to a number of the other goals (Table 3). Although many of the gaps and opportunities hold out promise for making minor contributions to many of the goals, these contributions are not shown in Table 3. In some instances, a gap or opportunity making a contribution to one goal may, depending on the specific R&D approach adopted, have negative connotations to another goal.

Table 3. Strategic Goals Addressed by Priority R&D Gaps and Opportunities.

	Goal*						
Gap/Opportunity	I	II	III	IV	V	VI	VII
Advanced fuel and vehicle concepts	•	+		•			•
Advanced natural gas technologies	+	•		•	•		
Analysis tools for electricity markets	•		+				
Indoor environmental quality	•			+			
International R&D partnerships				•	•	+	
Land and water impacts				+			
Long-term greenhouse gas technologies					+	•	•
Multi-attribute life-cycle analysis				+	•	•	
Non-petroleum energy supplies	•	+			•		
On-board hydrogen storage		•		•	+		
Real-time controls and measurement	•		+				

*A plus sign denotes primary relevance to a given goal and a dot indicates major relevance. No entry implies minor or no relevance to a given goal.

4.0 PORTFOLIO PLANNING OPPORTUNITIES AND NEEDS

During the course of the discussions and deliberations, and particularly during the identification of gaps and opportunities by goal, Panels II and III identified several important planning opportunities and needs for improving the overall effectiveness of entire Energy Resources R&D Portfolio. Development of the following items represents recommended portfolio planning opportunities and needs:

- an overarching energy R&D portfolio strategy addressing short-, mid-, and long-term time horizons;
- a long-term carbon and greenhouse gas management strategy, plan, and program evaluation metrics;
- comprehensive technology deployment strategies, both domestic and international;
- systematic planning mechanisms for linking science and applied R&D; and
- coordination plans for cross-cutting technologies and disciplines, including
  - biotechnology;
  - catalysts;
  - materials;
  - membranes;
  - sensors and controls; and
  - systems integration.

The overarching energy R&D portfolio strategy should embrace the International Clean Energy Initiative as well as contain a long-term clean fuels strategy including hydrogen. Both of these

activities are part of new DOE initiatives. This strategy should also incorporate appropriate methodologies, such as R&D road maps, visioning exercises, and scenario generation and analysis. The technology deployment strategies should include identifying and creating niche market introduction opportunities (e.g., small urban vehicles, smart buildings, and international applications) through a thorough understanding and analysis of competitive markets, interactions between technology and customers, and international trade policies. These long-term strategies should also reflect an understanding of the potential impacts of future greenhouse gas control options, such as carbon taxes, emissions permits, and emissions trading, on market opportunities for advanced technologies.

5.0 CONCLUDING REMARKS

The current assessment of the Energy Resources R&D Portfolio (February 2000) builds on a similar mid-1999 analysis. Many of the recommendations put forth by the previous analysis have been well received by DOE and acted on in a timely manner. Considerable evidence to this effect is present in the seven new initiatives undertaken by DOE since completion of the mid-1999 analysis. These initiatives encompass many of the gaps and opportunities identified in mid-1999 and are summarized as follows:

Initiative	Budget Request Fiscal Year 2001 ($ million)
Efficient and Affordable Buildings Research	10.3
Nuclear Energy Research	12.6
Ultra-Clean Transportation Fuels	17.5
Energy Grid Reliability	23.0
Power Generation Greenhouse Gas Reduction Technologies	44.4
International Clean Energy	45.7
Biobased Products and Bioenergy	48.5

Overall, although none of the strategic goals is judged to be addressed in a highly adequate manner, some of the subordinate issues are exceptionally well addressed, while others are relatively poorly addressed. As a result, few significant differences in the adequacy of the portfolio in addressing the seven strategic goals are present. In summary, the adequacy of the Energy Resources R&D Portfolio is assessed as follows:

Addressed Adequately:	Economic Productivity (Goal I)
	Oil Vulnerability (Goal II)
Conditionally Adequate:	Systems Reliability (Goal III)
	Health and Environmental Impacts (Goal IV)
	Greenhouse Gases (Goal V)
Addressed Inadequately:	International Cooperation (Goal VI)
	Future Choices (Goal VII).

Even given the new DOE initiatives, the Energy Resources R&D Portfolio is still judged to have some R&D investment gaps or opportunities remaining in important areas. The following priority gaps and opportunities are put forth as general suggestions to be carefully analyzed by DOE:

- long-term greenhouse gas stabilization technologies;
- real-time control and measurement, including intelligent power electronics, local demand management, and smart meters;
- analysis tools and models applicable to deregulated electricity markets;
- indoor environmental quality, including air quality, air exchange and moisture level, artificial and natural lighting, and human productivity considerations;
- multi-attribute life-cycle analysis, including health and environmental considerations;
- international technology partnerships and cooperative R&D;
- land and water impacts of materials flows;
- non-petroleum energy supply options;
- advanced concepts for fuels and vehicles (i.e., post Partnership for a New Generation of Vehicles);
- advanced technologies to meet expected natural gas demand increases (e.g., emphasis on western hemisphere resources and methane hydrates); and
- on-board hydrogen storage systems.

Notwithstanding the importance of these gaps in the Energy Resources R&D Portfolio, the portfolio planning opportunities that DOE needs to embrace in its longer term R&D planning and budgetary guidance represents the most significant message emerging from the current analysis. These planning opportunities and needs include development of:

- an overarching energy R&D portfolio strategy addressing short-, mid-, and long-term time horizons;
- a long-term carbon and greenhouse gas management strategy, plan, and program evaluation metrics;
- comprehensive technology deployment strategies, both domestic and international;
- systematic planning mechanisms for linking science and applied R&D; and
- coordination plans for cross-cutting technologies and disciplines, including biotechnology, catalysts, materials, membranes, sensors and controls, and systems integration.

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Appendix A - List of Participants

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Appendix B - R&D Council Presentation Slides