Estimating the Benefits of Government-Sponsored Energy R&D:

SYNTHESIS OF CONFERENCE DISCUSSIONS

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FOR THE DEPARTMENT OF ENERGY

This document is a summary of discussions at the conference on "Estimating the Benefits of Government-Sponsored Energy R&D," held on March 4 and 5, 2002 in Arlington, Virginia. The conference was organized by Oak Ridge National Laboratory (ORNL) and sponsored by the Office of Energy Efficiency and Renewable Energy; Office of Fossil Energy; Office of Nuclear Energy, Science and Technology; and Office of Science of the U.S. Department of Energy. The Conference Chair acknowledges, with thanks, the administrative and logistical contributions of Barbara Ashdown, Stephanie Floyd, Lesley Akers, Linda Armstrong, Tim Golden, Val Valentine, and other ORNL staff. Information about the conference is available on the conference web site: www.esd.ornl.gov/benefits_conference.

Environmental Sciences Division

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Estimating the Benefits of Government-Sponsored Energy R&D: SYNTHESIS OF CONFERENCE DISCUSSIONS

ABSTRACT

In 2001, a National Research Council (NRC) committee conducted a retrospective study of the benefits of some of the energy efficiency and fossil energy programs in the U.S. Department of Energy (DOE). As part of its study, the NRC committee developed a methodological framework for estimating these benefits. Following the NRC report, a conference was organized by Oak Ridge National Laboratory to discuss ways of adapting and refining the NRC framework for possible use by DOE offices to help plan and manage their R&D. This report is a synthesis of the discussions at the conference.

The following figure depicts a framework to categorize the benefits of government-sponsored energy R&D.

	Past	Future	
	Realized	Projected	Option Cases
Economic			
Environmental			
Security			
Knowledge			

The rows in this matrix reflect DOE's mission and objectives; they are the ultimate *outcomes* of the R&D activities. The columns reflect *when* the benefits occur and the scenarios or degree of *certainty* under which they might occur.

Many approaches were suggested for estimating the benefits within each category and many challenges in making these estimates were noted as well. Many conference participants suggested that DOE could use prospective, as well as retrospective, estimates of its programs' benefits to help plan and manage its R&D portfolio.

Estimating the Benefits of Government-Sponsored Energy R&D: SYNTHESIS OF CONFERENCE DISCUSSIONS

SUMMARY

Background

Government investment in R&D is the engine that drives advancements in science and technology for the public good. These investments must be made wisely. Under the Government Performance and Results Act of 1993 (GPRA), federal agencies are required to report annually on their programs' plans and performance. Furthermore, the President's Management Agenda for Fiscal year 2002 called for better R&D investment criteria, with the U.S. Department of Energy (DOE) piloting this initiative.[1] In Congress, the Appropriations Committee of the U.S. House of Representatives requested that the National Research Council (NRC) conduct a retrospective study of the benefits of some of DOE's energy efficiency and fossil energy programs.[2] As part of its study, the NRC committee developed a methodological framework for estimating the retrospective benefits of some of DOE's programs.

Offices in DOE are giving priority to measuring and assessing the performance of their R&D programs. As part of these ongoing efforts, the energy resource and science offices co-sponsored a conference on March 4 and 5, 2002 to gain insights that they might use to improve their methods for estimating the benefits of their R&D programs. The conference participants consisted of 150 experts in R&D program assessment, planning, and management; and in the specialized methods used in these activities. They were from federal and state government, industry, academia, and private research organizations.

The conference built on the NRC framework, and considered ways of adapting and refining it for possible use by DOE offices for their GPRA and other performance management needs. This report is a synthesis of the discussions at the conference.

[1] Executive Office of the President, Office of Management and Budget, *The President's Management Agenda, Fiscal Year 2002*, August 2001. National Energy Policy Development Group, *National Energy Policy*, Washington, DC, May 2001.

[2] National Research Council's Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, *Energy Research at DOE: Was It Worth It?*, Washington, DC: National Academy Press, July 2001.

Benefits Framework

The NRC committee developed a framework for retrospective analysis that is represented by a matrix with three rows and three columns. The rows reflect DOE's energy-resources programs' strategic objective: to provide economic, environmental, and security benefits. The columns reflect the degree of uncertainty about the possible commercialization of the technologies that result from the R&D. On this dimension, the NRC committee categorized the benefits as: realized, option, and knowledge benefits.

The NRC framework appeared to hold up well to conference participants' scrutiny. However, three modifications to the framework were recurring themes in the discussions:

- New Column for Projected Benefits. Many participants suggested that the matrix have a new column to account for the DOE offices' need to make *prospective* assessments of the benefits of their R&D programs. The new column would represent benefits under a projected base case scenario.[3] This modification would assist these DOE offices to integrate their assessments of the prospective and retrospective benefits of their programs, for the purposes of program planning and evaluation.

- Columns of the Matrix Have Varying Degrees of Certainty. Several participants suggested that the columns of the matrix represent scenarios that have varying degrees of certainty -- the past; the projected base case (as suggested above); and other future "option cases." Many participants thought that R&D has option value because it provides insights and capabilities that could have value in the future.

- Knowledge as a Row of the Matrix. Many participants suggested a change in the way in which knowledge benefits are considered, so that they are represented by a row in the matrix rather than by a column. This change reflects the fact that knowledge is a core mission of the science programs in DOE, as well as of some of the energy resource programs. Also, many participants thought that various types of knowledge are enablers of innovation. They suggested that knowledge could be viewed as a third dimension of the matrix to convey the idea that various types of knowledge contribute to other types of benefits.

The idea of option cases (e.g., scenarios that are less probable than the base case projection) expanded on the concept introduced in the NRC (2001) report. Many participants favored an option approach in the R&D planning process because the outcomes of R&D are inherently uncertain, as are future economic, geopolitical, regulatory, and policy conditions. Several conference participants noted that planning for less-probable scenarios is an integral aspect of DOE's mission.

[3] This idea was one of the "strawperson" suggestions made in the white paper distributed prior to the conference: Lee, R., Wolf, J.L., Zimmerman, M.B., Braitsch, J., Vallario, R., Powell, J., and R.C. Ricci, "Ideas on a Framework and Methods for Estimating the Benefits of Government-Sponsored Energy R&D," Oak Ridge, Tennessee: Oak Ridge National Laboratory.

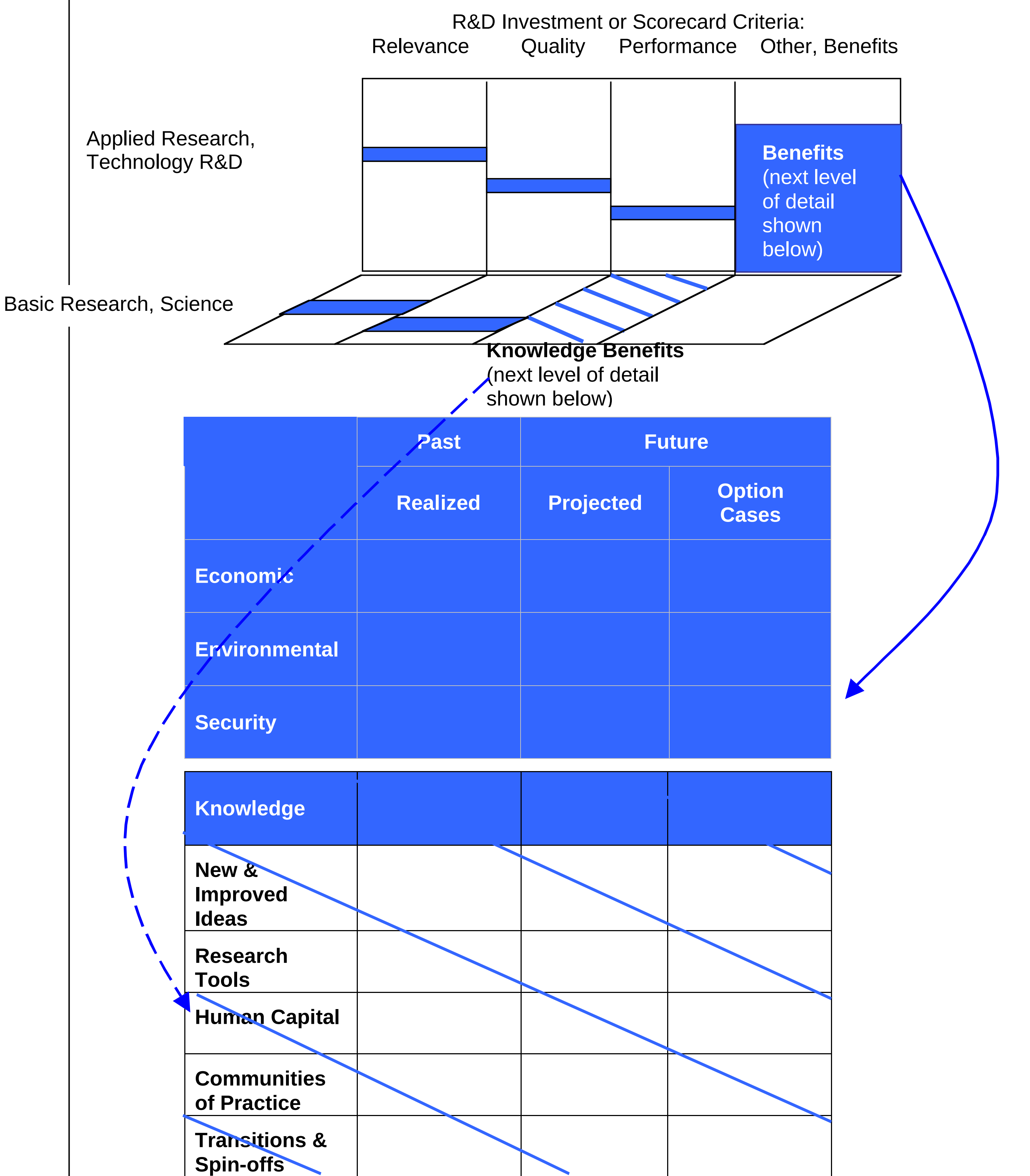

Figure S1. Framework for Estimating the Benefits of Energy R&D
(Blue-Shaded Areas Represent Benefits-Related Metrics)

Many opinions were presented about the methodological framework. Figure S1 presents a figurative synthesis of conference participants' suggestions. No consensus was sought at the conference, however, and this figure was actually *not* constructed during the conference. It is offered here as a reasonable synthesis of many of the salient ideas about the framework that emerged during the discussions.

The top part of the figure casts the framework within the broader context of a program evaluation scorecard, or of possible R&D investment criteria. Benefits-related measures could fall under several different categories, as represented by the blue-shaded areas. These areas could be criteria such as the "public benefit" aspects of a program, or the "commercial timeframe" of the technology being developed.

The middle part of the figure is an adaptation of the NRC matrix in which knowledge is no longer represented by a column of the matrix, but by a row. Many participants in the conference workshop on knowledge benefits suggested that knowledge is also a third dimension of the other cells of the matrix because knowledge contributes to virtually all of the outcomes of technology R&D programs.

The participants suggested further that knowledge benefits could be expanded into five categories. This idea is reflected in the bottom part of figure. These benefits would pertain principally to the science programs. Conference participants similarly offered many types of economic, environmental and security benefits. Many conference participants suggested that such a framework, or something similar to it, could be adapted and implemented DOE-wide, or at least among the offices involved in the conference.

Many conference participants considered the projected baseline conditions, and the market penetration of the new technology that would be the result of the R&D, as two of the more important factors that affect estimates of a program's benefits. The projected baseline establishes the next-best alternative and the conditions upon which the new technology is to be introduced. Many conference participants suggested that the Reference Case, used in the Energy Information Administration's (EIA's) *Annual Energy Outlook* (AEO), could be a starting point for defining both the projected baseline conditions and the market penetration of the new technology. EIA's Reference Case is generated using the National Energy Modeling System (NEMS), which is a large-scale integrated model of energy markets and technologies.

Many conference participants suggested, however, that NEMS is limited in its representation of specific types of technologies. To address this limitation, several conference participants suggested models that could more easily characterize new technologies, such as the MARKAL model. If used, these other models would be calibrated to the NEMS AEO Reference Case.

However, other conference participants considered that any large-scale model is inherently limited in making accurate long-term projections. They argued that information gathered from direct face-to-face discussions with industry, stakeholders, and other knowledgeable parties could be more reliable than the projections of any model. Several participants suggested that such case studies could be used to augment model-based results.

In addition to DOE's contribution, the private sector and possibly other organizations generally contribute significantly to the success of a new technology that is developed in part through DOE funding. An important concern among many conference participants was that the impact of the government on the overall success of a technology should be properly considered. Conference participants identified different ways of estimating the impact of the government. One approach was a generalization of the so-called 5-year rule defined by the NRC study, which assumes that the impact of the government's share of the R&D is to accelerate commercialization of technologies by five years. Many conference participants favored a generalization of the rule to account for the idea that the government's acceleration of the commercialization process would vary, depending on the type of technology as well as on many other factors. Many conference participants thought that the prospective impact of the government on commercialization could be estimated on a case-by-case basis and that such assessments should be transparent, clear, and peer reviewed. An approach supported by several participants was to have direct discussions with companies involved in the technology.

Estimating the Various Benefits

Conference participants offered many different measures for security, economic, environmental, and knowledge benefits. Many conference participants agreed that it might be appropriate to have more than one measure for any given type of benefit.

In addition to the economic value of the reduction in energy consumption and costs, a measure used by several DOE offices, conference participants noted other measures and methods for estimating economic benefits, such as:

- A cost index based on expected consumer costs, with and without the new technology,
- Econometric analysis to estimate spillover and macroeconomic impacts of sector-wide R&D investment, and
- Case studies (which can be used for estimating other types of benefits as well).

In addition to the estimates of reduced emissions of criteria pollutants and carbon dioxide now used by several DOE offices, conference participants noted other measures and methods for estimating environmental benefits, such as:

- An Index of Sustainable Economic Welfare, based in part on impacts on ecosystem services (which have been estimated on a dollar per hectare basis for different types of ecosystems), and
- Economic approaches for valuing environmental benefits such as: hedonic analysis (econometric methods to identify relationships between the value of economic assets such as property values and environmental attributes such as air pollution); contingent valuation (economic experiments to estimate individuals' valuing of environmental damages avoided); and direct measures of market value (such as lost productivity or crop yield).

In addition to the estimates of reduced oil consumption, which some DOE offices use, conference participants suggested many indicators of energy security benefit, including:

- Supply and demand conditions such as energy import levels, diversity of energy supply, and insurance rates and costs for protecting energy infrastructure;
- System flexibility and sensitivity, such as price elasticity of U.S. demand for various fuels, substitutability, fuel stocks, and macroeconomic sensitivity to energy shocks; and
- Reliability/volatility measures such as the frequency and duration of interruptions (e.g., power outages), grid reliability (e.g., power quality), capacity to meet peak energy demands, transmission congestion costs, and surveys of public confidence about energy security.

Knowledge-based capacity benefits were identified as including generation of new or improved ideas, research tools, human capital, and communities of practice. These benefits increase agility and capacity for research, and opportunities to transition or apply knowledge, which in turn lead to benefits in the market place. Suggested indicators and methods included:

- Expert judgement on the quality, relevance, progress and prospects of the research.
- Analysis of publications, citations and patents (bibliometric methods) that consider, for example, patents that cite papers and patent portfolios, to identify the networks and linkages between science and technology innovation -- insights that could be applied prospectively as well as retrospectively;
- Technical milestones attained, in cases where these can be projected;
- Number of graduate students trained;
- Connectivity of communities of practice; and
- Intellectual property generated.

Many participants discussed that some of these approaches are not yet well defined for GPRA- or performance-based applications, or are costly to implement. They suggested a phased, multi-year approach to add metrics to improve the performance management of DOE's programs.

Program Planning and Decision Making

For program planning and decision making, many conference participants thought it important to view individual programs as part of a broader energy R&D portfolio, particularly given the long time frames and risks in developing successful technologies. Many conference participants regarded estimates of benefits as but one criterion in R&D investment decisions. Other criteria could include the R&D's time frame, program cost, and technical risk. Many conference participants favored the use of visual representations of portfolio analyses. These graphics depict the interplay and trade-off among decision criteria.

The importance of portfolio management was highlighted by several conferees. The workshop on option value discussed the need to cut across

DOE stovepipes to assess the benefits of R&D portfolios. Decisions to terminate a program were regarded by many as being as important to consider as those to initiate or continue one.

A few conference participants cautioned against relying too much on complicated frameworks and methodologies. They reminded conferees that there is no substitute for "common sense" in R&D program planning and evaluation.

Certain themes tended to surface frequently throughout the conference. Many participants appeared to agree on the need to have a uniform framework that would be tailored to capture programmatic differences but used across all relevant DOE offices. They stressed the importance of having a consistent projected baseline and assumptions, which all offices would use. They thought the methods should be transparent, and that methods and assumptions should be peer reviewed. Many participants also agreed on the need to continually improve the methods for estimating the various types of benefits and to do pilot testing of these methods on selected programs before implementing them office-wide.

Figure S2. Among the conference participants who offered suggestions on methods to estimate the benefits of government R&D were: (1st row) Bob Vallario, Office of Science, U.S. Department of Energy (DOE); Jeanne Powell, Economic Assessment Office, National Institute for Standards and Technology; (2nd row, L to R) Marilyn Brown, Oak Ridge National Laboratory; Bob Dixon, Office of Energy Efficiency and Renewable Energy (EERE), DOE; Gerald Pine, Gas Technology; Tony Bournakis, University of Illinois at Chicago; and Sam Baldwin, EERE, DOE.

Conference on
Estimating the Benefits of Government-Sponsored Energy R&D
March 4 and 5, 2002
Arlington, Virginia

SYNTHESIS OF CONFERENCE DISCUSSIONS

Background and Overview

A conference on "Estimating the Benefits of Government-Sponsored Energy R&D" was held on March 4 and 5, 2002. Its purpose was to gain insights about methods, which the energy resource and science offices of the U.S. Department of Energy (DOE) might use to improve their assessment of the benefits of their R&D programs for the purposes of program planning and measuring their performance. The conference was organized by Oak Ridge National Laboratory (ORNL), and was sponsored by DOE's offices of Energy Efficiency and Renewable Energy (EERE), Fossil Energy (FE), Nuclear Energy, Science and Technology (NE), and Science (SC). There were 151 participants including: senior DOE management; DOE R&D program managers; R&D program managers from other federal agencies; staff of the Office of Management and Budget (OMB); staff from the General Accounting Office (GAO); Congressional staff; stakeholders; researchers and analysts from universities and national laboratories; and consultants and contractors.

Figure 1. Mike Smith, Assistant Secretary of the Office of Fossil Energy, U.S. Department of Energy (DOE); Russell Lee, Conference Chair, Oak Ridge National Laboratory; and Douglas Brookman, Conference Facilitator, Public Solutions, Inc. (left to right) listen to Loretta Beaumont, Chief of Staff, U.S. House of Representatives Subcommittee on Appropriations for Interior and Related Agencies as she discusses her desire for DOE to establish objective methods that can be applied consistently across all of its programs to estimate the benefits of their R&D.

The motivation for the conference stemmed from a widespread desire among Congress, the Executive Office of the President, GAO, and DOE to undertake a thorough performance-based approach to planning, managing and evaluating federal R&D investments. All of these parties are placing great emphasis on improving the implementation of the Government Performance and Results Act of 1993 (GPRA) which requires federal agencies to report annually on their programs' plans and performance.

Figure 2 illustrates relationships between the inputs to an R&D program (i.e., the resources devoted to it) and its ultimate, end outcomes. Various research-planning scorecards, R&D investment criteria, GPRA data calls, and other metrics have been used as performance-based measures of R&D success. The more recently proposed metrics have placed greater emphasis on assessing the out*comes* of the programs' performance -- their longer-term impacts and benefits -- in addition to their out*puts* such as program deliverables and milestones. Thus, regardless of the specific scoring system or investment criteria used to evaluate programs, one would expect that their estimated benefits -- both retrospective and prospective -- will be a key performance measure.

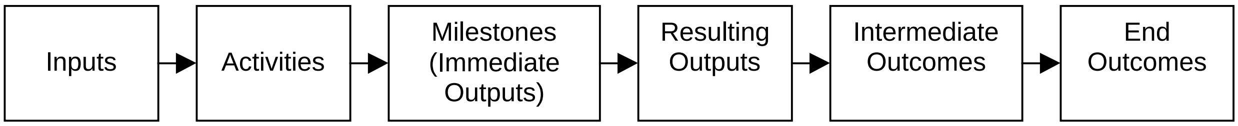

Figure 2. Logical Flow of R&D Inputs, Activities, Milestones, Outputs and Outcomes

A recent National Research Council (NRC) report, which was requested by Congress, assessed the performance of many of DOE's energy efficiency and fossil energy technology programs by estimating their retrospective benefits.[4] The methodological framework developed by the NRC study was the basis for a strawperson framework that provided a starting point for discussions at the conference.[5]

The conference consisted of plenary sessions and four workshops. The plenary sessions presented the objectives of the conference, challenges to improve the methods used by DOE offices, and summaries of various methods that they and other federal agencies currently use. Each workshop focused on a key methodological issue(s) related to the structure and refinement of the NRC framework and to the methods for estimating the various types of benefits within the refined framework.[6] The primary focus in all of these discussions was on a consistent framework for measuring the benefits of R&D, and on methods for estimating them, which the DOE offices could begin to implement.

Figure 3. Mike Smith, Assistant Secretary of the Office of Fossil Energy (FE) in DOE, challenged conference participants to address some of FE's key needs in assessing the benefits of its R&D.

Many different methods were mentioned among conference participants for the various types of benefits, within the overall methodological framework. Given the limited time available at the conference, its participants purposefully focused on the "forest and not the trees." Thus, conference participants generally did not offer detailed descriptions of specific methodologies. Instead, participants focused more on the general methodological framework and on its key

[4] National Research Council's Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, *Energy Research at DOE: Was It Worth It?*, Washington, DC: National Academy Press, July 2001.

[5] Lee, R., Wolf, J.L., Zimmerman, M.B., Braitsch, J., Vallario, R., Powell, J., and R.C. Ricci, "Ideas on a Framework and Methods for Estimating the Benefits of Government-Sponsored Energy R&D," Oak Ridge, Tennessee: Oak Ridge National Laboratory, February 27, 2002. This "white paper" is available on the conference web site: www.esd.ornl.gov/benefits_conference.

[6] The workshop rapporteurs' summaries of each of the four workshops are available on the conference web site: www.esd.ornl.gov/benefits_conference.

concepts, and referred to the *general types* of methods that could be used to estimate the various types of benefits.

The rest of this report summarizes the major topics discussed at conference. Table 1 provides some of the highlights.

Table 1. Major Issues Raised and Needs for Refinement in the Benefits Matrix

Aspect of the Framework	Nature of the Caveat or Suggested Refinement
Overall framework	• Defining carefully the interaction and relationships among the different benefits categories to ensure that they are well-defined and non-overlapping
	• Considering refinements to the matrix such that the *columns reflect the time dimension and uncertainty* [i.e., past, projected, and option cases] and *the rows represent DOE strategic objectives* [i.e., energy security, economic, environmental, and knowledge benefits]
	• Developing better ways of attributing the impacts of the government R&D program within the overall success of a technology
Economic impacts	• Identifying and estimating important second-order benefits such as improved productivity, spillover effects, and macroeconomic benefits
	• Considering equity and the distribution of impacts among different parts of society
Environmental impacts	• Considering other types of environmental impacts such as ecosystem services
Security impacts	• Recognizing and estimating the many different types, and the interdependence among, security impacts and benefits
Prospective benefits	• Defining precisely what is meant by the base case, business-as-usual case, or reference case
	• Developing methods to define a common set of baseline assumptions, and to calibrate analyses and models to this baseline
Option value	• Recognizing that real options valuation is a well-established investment-management approach that

	estimates the benefits of R&D by taking *advantage* of the uncertainty and risks about both the ultimate technical performance of the technology and future economic and regulatory conditions (perhaps initially implementing this concept with a scenarios approach, as a simple, alternative means of characterizing the value of R&D under uncertain futures)
Knowledge value	• Modifying the matrix so that knowledge, which is a core mission of the science programs, is a row of the matrix, and also a third dimension in all other benefits, rather than a column of the matrix
Use of the framework	• Addressing the variability in program timeframes and the timing of their future benefits and costs
	• Developing practical cost-effective ways of implementing and putting into practice the framework, the estimation methods, and case studies
	• Developing an office-wide, or possibly business-line, approach to assessing and planning the *portfolio* of R&D programs using estimates of their benefits and other key performance measures

Setting the Stage: Current Practices and Challenges

The Assistant Secretary of the Office of Fossil Energy in DOE and the Chief of Staff of the U.S. House of Representatives Subcommittee on Appropriations for Interior and Related Agencies challenged conference participants to address some of their key needs:

- identifying the benefits of the R&D carried out by various DOE programs,
- setting criteria for estimating the prospective benefits of these programs,
- establishing objective methods that can be applied across all programs, and
- having practical ways of improving the programs and for communicating their benefits.

DOE senior staff described their current approaches for estimating the benefits of their programs. In one presentation, the EERE staff member discussed that EERE has begun to implement many of the methods developed in the NRC study. She noted the types of benefits within NRC's framework, which EERE is currently estimating; the types of benefits which it is planning to address; and those for which little study has been done thus far. She also noted that EERE is planning to integrate, over the next several years, its estimating of retrospective and prospective benefits. The FE staff member reviewed the two different R&D areas in FE: fossil fuel conversion and domestic supply. Different evaluation methods and models are used for each. NE staff discussed the diverse R&D

areas within that office: nuclear power, medical diagnostics and therapeutics, space, defense, and industrial applications. Allocation of resources to these areas is based on priorities to maintain current streams of benefits, expand programs and their benefits, or abandon them. The SC staff member pointed out the inherent difficulty in characterizing the value of new knowledge. He reviewed methods SC currently uses to assess its programs such as peer review and cost-schedule milestones. He noted that although scientific progress is often serendipitous, methods for linking science to energy portfolios are indicators of the value of science to applications that benefit society.

Staff from other federal agencies, specifically the Advanced Technology Program (ATP) in the National Institute of Standards and Technology (NIST), and the Volpe Center in the U.S. Department of Transportation (DOT), described some of the methods they use:

- estimates of outputs (e.g., number of R&D partners), intermediate outcomes (e.g., acceleration of commercial activity), and impacts or ultimate outcomes (e.g., economic benefits),
- business reporting systems, supplemented by telephone surveys,
- case studies of the return on investment and the net present value of programs,
- macroeconomic analyses,
- composite performance ratings of program performance, based on knowledge creation and dissemination, commercialization, and technology diffusion,
- fault-tree analyses to identify causes of damaging events (accidents, in the case of DOT) and the potential benefits of technology R&D to address them, and
- assessments by experts.

A senior OMB manager discussed the priority given by the current administration to improving accountability in government. He discussed the need to be able to communicate the benefits of R&D clearly and simply, and to be able to discriminate among different programs. He made the point that OMB is skeptical of using knowledge benefits as justification for *applied* research. He emphasized the need to have better estimates of the government's contribution to the overall benefits of the technologies associated with an R&D program, and reiterated that performance-based assessments of R&D programs are one of the administration's top management objectives.

Figure 4. William Magwood, Director of the Office of Nuclear Energy, Science and Technology, DOE (Left), shown here with Shane Johnson also of NE, DOE, described NE's approach for doing "the right R&D."

The conference's keynote speakers highlighted, respectively:

- NE's systematic approach for doing the "right R&D": understanding the big picture and the needs, determining the technology goals, deciding how to reach these goals, deciding who performs the work, and continuously reassessing scope, performance and quality. [William D. Magwood, IV, Director of the Office of Nuclear Energy, Science and Technology, DOE];

- EERE's commitment to improving its methods for estimating the benefits of its R&D, and the importance of results-oriented GPRA evaluations of their programs to ensure that EERE is delivering the best possible improvements in energy efficiency and renewable energy to the country's taxpayers. [David K. Garman, Assistant Secretary of the Office of Energy Efficiency and Renewable Energy, DOE]; and

- The great importance of performance-based assessment and the GPRA process to this administration, the usefulness of measuring *intermediate* outcomes in the long-term R&D process, and the recognition that the final outcomes of R&D programs might be too distant to effectively defend their value. [Joseph S. Wholey, Professor at the University of Southern California and, recently, senior advisor at GAO].

Members of the NRC Committee that authored the aforementioned report described the origins and motivation for the study. They recalled that some in Congress questioned the magnitude of the benefits of government R&D. The Chair of the Committee pointed to key challenges in taking the next steps from their study: the need to account for uncertainty in prospective analysis; the need to have consistent, transparent, and tractable methods; and the need for rigorous rules for things that are fuzzy (such as the impact of the government on the success of a technology). The Chairman of the Committee's Subgroup on the Benefits Framework then outlined the framework and its rationale. The framework is described more fully in the NRC report, and is summarized in the white paper that was distributed prior to the conference.

The Conference Chairman then offered some thoughts on the priorities, challenges, and "strawman" ideas for building on the NRC framework so that DOE offices could improve their methods for estimating the benefits of their R&D programs for the purposes of GPRA reporting, program planning, evaluation and budgeting. These methodological challenges were the basis of the conference's four workshops that focused, respectively, on:

- cross-cutting issues in estimating prospective benefits;
- option value;
- the benefits of knowledge; and
- security, economic, and environmental benefits.

This report is a synthesis of the discussions in the four workshops. Consensus or recommendations were not sought from conference participants. The remaining sections of this report synthesize conference participants' views on:

- a general methodological framework, adapted from that developed by the NRC committee,
- measuring and estimating retrospective benefits,
- measuring and estimating prospective benefits,

- option value,
- economic benefits,
- environmental benefits,
- security benefits
- knowledge benefits,
- data sources, and
- use of estimated benefits in program planning and evaluation.

Framework for Estimating the Benefits of R&D Programs

The starting point for discussions in the conference's workshops was described in the conference white paper as the NRC committee's methodological framework for estimating R&D benefits, with the addition of a category for projected prospective benefits. The reason for adding this category was that GPRA analysis, planning, and budgeting of R&D programs all require prospective assessments of the value or return on the R&D investment. The NRC matrix was developed solely for a retrospective assessment. That is, the NRC study was about the past success of programs, whereas program planning and budgeting must also estimate the future success toward which DOE's R&D programs are striving.

The white paper offered some "strawman" approaches and suggested that a matrix with three rows and four columns could be used to represent the methodological framework. Following the basic idea of the NRC framework, the white paper suggested a matrix that has three types of impacts listed along one dimension of the matrix (i.e., the rows): economic, environmental, and security. These impacts reflect the core objectives, or ultimate outcomes, toward which the DOE R&D enterprise is striving. The other dimension of the matrix (i.e., the columns) reflects the degree of certainty about the specific commercial benefits of the R&D and categorized benefits as being: realized, prospective base case, options, or knowledge.

Figure 5. Robert Fri, Chairman of the National Research Council (NRC) Committee that estimated the benefits of some of DOE's programs, describes the NRC methodology.

Realized benefits are those that have already occurred as a result of past R&D. Prospective base-case benefits are estimates of future benefits under a base case scenario. When there is uncertainty about future conditions, option benefits are the value of an asset (e.g., a technology) that provides the ability to retain choices that can be implemented in the future. Knowledge benefits are those associated with the immediate insights, ideas and research tools gained from scientific studies; and with the effects of the scientific process on human capital, and on scientific and technical communities of practice.

With such a diverse and expert group of conference participants, it was not surprising that conference participants' discussions about adapting the NRC framework to consider benefits prospectively, as well as retrospectively, resulted in a rather thorough scrutiny and critique of the framework. Some conference participants thought it was too complex. They favored using fewer measures of a program's benefits and success, and more "common sense" in making such assessments. Other conference participants thought the framework was overly simplified and restrictive about certain types of benefits such as security and knowledge, and argued for a more complex and comprehensive framework.

In the end, however, many conference participants appeared to find the framework to be generally acceptable and useful as part of a larger framework for R&D planning and evaluation -- albeit with suggestions for its expansion or refinement.

One of the major modifications of the NRC framework, suggested by many conference participants, was to represent knowledge benefits more meaningfully from the perspective of those engaged in planning and assessing basic research programs. Many of the participants in the workshop on knowledge benefits thought that the creation of "knowledge," being a core objective of DOE, should be a row in the matrix. Furthermore, these conference participants viewed knowledge as a third dimension of the matrix, underlying all of the benefits of applied research and technology programs. Their idea reflects their point that knowledge interfaces with, and is an input to, all other benefits. Others at the conference, on the other hand, favored retaining the NRC matrix for use with applied research programs, with knowledge as a column; and using a separate matrix for the science programs. Many participants in the workshop on knowledge benefits also generally accepted the idea of knowledge as a "thin" column in the matrix for the applied research programs, that is, as an enabling but not primary category for the analysis of their benefits.

Many conference participants favored adding a column to the matrix to represent projected benefits. A few participants did not relate to the idea of having such a prospective-benefits column, however; and some favored using two different matrices for retrospective versus prospective assessments.

Several participants in the workshop on option value questioned the need to have a projected-benefits column, or for that matter a knowledge column in the matrix. For these participants, real options valuation is a complementary alternative to net-present-value analysis -- but is not added to these benefits. These participants generally deferred, however, to others in the workshop concerned about the amount of information needed for a comprehensive option valuation. The latter group of participants also cautioned that the real options paradigm, although promising, is so different from current practice in DOE that it would have to be introduced *gradually* into its R&D management and benefits-estimation activities.

Figure 6 represents a synthesis of many of the various viewpoints, shaped into an integrated framework. Here, the "End Outcomes" box in Figure 2 is placed into the broader context of criteria for assessing whether to invest in R&D and is also expanded into its basic categories. Figure 6 was actually *not* constructed during the conference, but is offered as a reasonable synthesis of many of the salient ideas about the framework that emerged during the discussions.

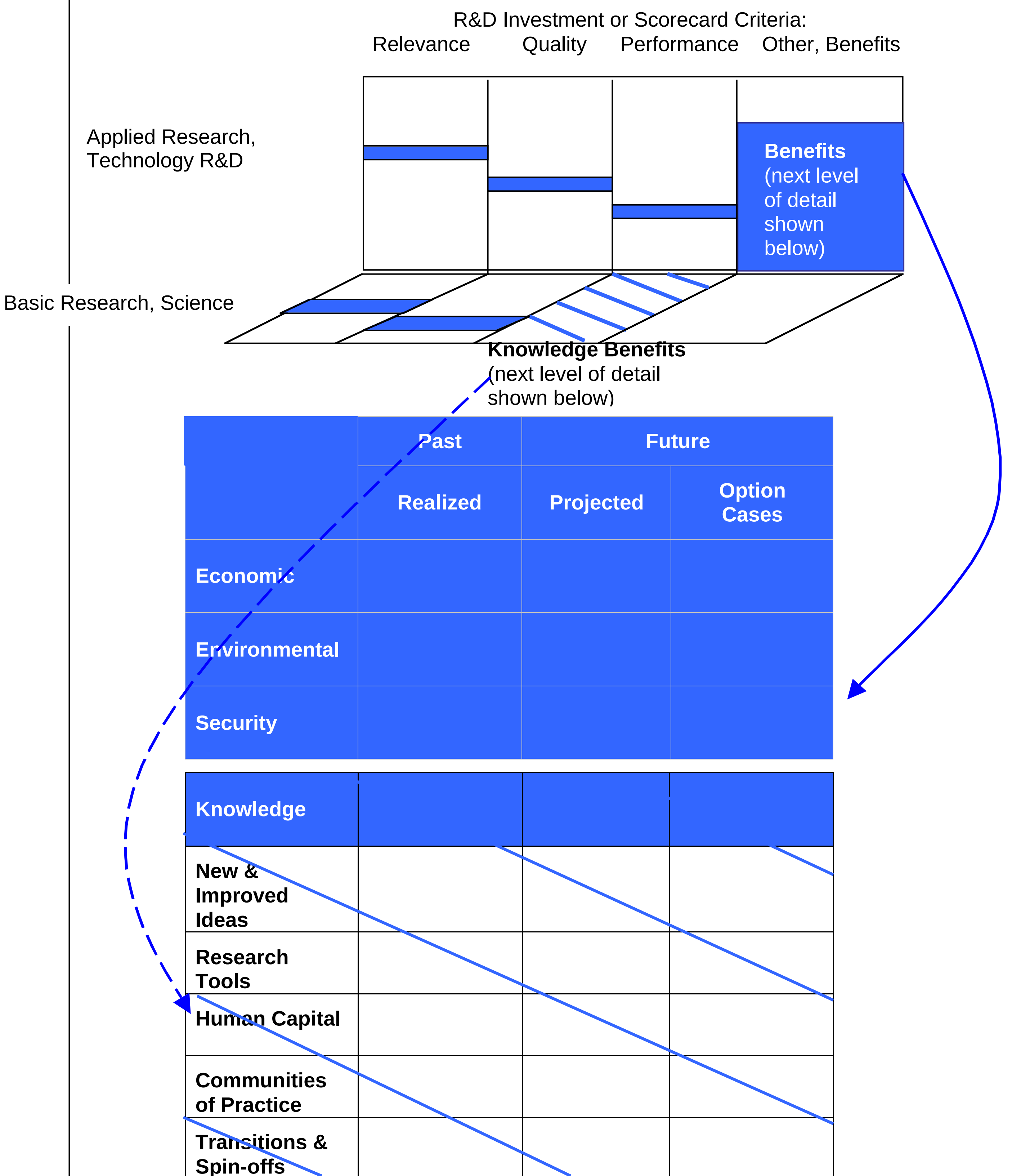

Figure 6. Framework for Estimating the Benefits of Energy R&D
(Blue-Shaded Areas Represent Benefits-Related Metrics)

The top part of the figure represents the fact that "benefits" can be viewed as one set of many possible performance measures. In the figure, the blue-shaded areas represent benefits-related measures. R&D evaluation or investment "scorecards" also typically include criteria such as "relevance" and "quality." Benefits-related measures could be relevant to several different criteria, as represented by the blue-shaded areas under those categories. Examples could be the "*public* benefit" aspects of a program, or the "commercial timeframe" of the technology being developed.

The middle part of Figure 6 is a "drilling down" of the benefits of applied R&D programs to the next level of detail. The figure reflects modifications to the NRC framework, which many conference participants appeared to favor:

- A new column to accommodate *prospective* assessments of the projected benefits of R&D programs, so that DOE offices can integrate their assessments of the prospective and retrospective benefits of their programs for the purposes of program planning and evaluation.

- The columns of the matrix represent scenarios of varying degrees of certainty -- the past (the realized benefits that apply only to retrospective assessments); the projected base case; and other option cases.

Knowledge benefits represented as a row rather than as column in the matrix, to reflect the fact that knowledge is a core mission of most of the science programs, as well as of some of the energy resource programs. Also, many participants in the workshop on knowledge value thought that the knowledge row should be in a third dimension of the other rows, to reflect their view that knowledge is an enabler of innovation that contributes to all other types of benefits.

The bottom part of Figure 6 is a "drilling down" to obtain the next level of detail about the knowledge benefits that result from basic research programs and from the process through which applied research programs lead to commercialized technologies. This "sub-framework" reflects many of the suggestions that emerged from the workshop on knowledge value.

The suggested refinements of the matrix that emerged from the conference would allow the applied and basic research programs to be viewed under a single framework. Perhaps more importantly, the refined framework conveys the integrated nature of knowledge as a foundation for all other types of benefits.

Many suggestions emphasized the multi-faceted nature of the individual categories of benefits (e.g., security is not a simple number) and the challenges in estimating them. Some conference participants noted that just as the middle and lower parts of Figure 6 represent a drilling down of parts of the upper section of the figure, each cell of the framework can be drilled down to access information about the specific nature of the benefits in that cell.

Figure 7 illustrates the evolution of the benefits framework, beginning with the one developed in the NRC study, to the one suggested in the white paper distributed prior to the conference, to the one that appeared to emerge from the conference's discussions.

NRC Matrix:

	Realized	Option	Knowledge
Economic			
Environmental			
Security			

⇩

Strawperson Matrix in White Paper:

	Realized	Expected Prospective	Option	Knowledge
Economic				
Environmental				
Security				

⇩

Framework that Emerged from the Conference:

	Past	Future	
	Realized	Projected	Option Cases
Economic			
Environmental			
Security			
Knowledge			

Figure 7. Refinement of the NRC Benefits Framework

A frequent theme of comments at the conference was that R&D programs and their estimated benefits should be considered collectively in deciding on an overall R&D portfolio, where benefits are one of several investment criteria. Thus, in the near term, DOE offices could use this framework and their existing analysis tools to estimate the more important types of benefits for each of their major programs. To ensure comparability among estimates, DOE offices could use the same framework, measures of each type of benefit, projected baseline conditions (to the extent possible), and other common input assumptions. Several conference participants suggested that, in the longer term (i.e., over several years), these DOE offices could improve the analysis tools they use for the more important categories of benefits that pertain to the more important programs of the department.

However, several participants cautioned against overreaching -- incorporating too complex a framework when the data to support it are limited in scope, detail or precision. Some participants suggested that common-sense rankings and peer reviews are a more sensible route to take than complicated modeling.

Many conference participants emphasized that there are many different types of benefits and, thus, different measures of these benefits. Many alternatives were mentioned, but conference participants frequently suggested the need for simple measures and methods, where possible; and for DOE offices to use the same non-overlapping measures and indicators, and consistent units or reference points. Conference participants did not resolve, however, how many types of measures, and the level of specificity, DOE might use.

In the next sections of this report, we synthesize participants' suggestions for each category or type of benefit, following the framework of the benefits matrix that appeared to emerge from the conference.

Retrospective Benefits

Definition of Retrospective Benefits

Retrospective benefits are those that are the result of past R&D. They include benefits that have already been realized, plus the value of any continuing benefits under the projected case as well as those under alternative future scenarios (i.e., option benefits).

Retrospective benefits could be measured in the following areas --

- Energy savings, reduced emissions, and reduced oil consumption associated with deployment and use of a technology whose development was partly the result of past DOE-sponsored R&D.

- Other types of economic, environmental and security benefits (refer to the discussions of these benefits in later parts of this report).

- Knowledge-related benefits (see later discussion).

Methods for Estimating Retrospective Benefits

Methods to estimate retrospective benefits could account for the following:

- Energy savings, cost savings and knowledge -- compared to those estimated for a counterfactual, next-best alternative. For many participants in the workshop on knowledge, the counterfactual alternative for "knowledge" is "none" when the advance is a breakthrough.

- Benefits and costs that occurred in the past or that are expected to occur with a high degree of certainty even if the R&D program were immediately terminated. The NRC committee credited the life cycle benefits of technologies that it projected to be deployed up to the year 2005 because benefits of prior R&D could extend beyond the 2000-2001 timeframe of the NRC study.

- Advances in knowledge-based capacity as measured primarily by peer review and citation and patent analysis.

Retrospective benefits are important for reporting on the past performance of programs, as required by GPRA. In fact, some conference participants thought that the conference should also have devoted greater attention to retrospective benefits than to prospective benefits.

Several aspects of the calculation of retrospective benefits that deserve some consideration, but which were not discussed at the conference are:

- The high cost of acquiring data on the past market penetration and use of technologies developed from DOE programs. For retrospective analysis, the NRC approach requires data on the historical, annual use of energy technologies -- data that DOE does not compile.

- (Inverse) discounting of past benefits and costs -- should the discount rate be applied inversely to past years' benefits and costs?

- Should the projected deployment of a technology up to the year 2005 (or over whatever near-term time horizon) be counted as realized benefits even though they occur in the future? This approach implicitly assumes that if the technology is already being used, then sales would continue over the next five years, even if the R&D program were completed or terminated. If that is the case, then these benefits would count as a *past* success, but would not count toward its *prospective* benefits.

Prospective Benefits

Definition of Prospective Benefits

Prospective benefits are the result of ongoing R&D or contemplated future R&D that is not yet funded. They include the benefits under the projected base case scenario, as well as option-related benefits (refer to later discussion about option benefits). Prospective benefits could be measured analogously to retrospective benefits:

- Economic, environmental, and security benefits from future deployment of the technology, net of any additional cost of the new technology, compared to the next-best alternative. These benefits include those from future outputs of ongoing research but *not* the benefits that might accrue in the future as a result of *past* R&D outputs.

- As in the case of retrospective benefits, the benefits (and costs) are relative to the next-best alternative. For prospective analysis, this next-best alternative is reflected in the projected baseline conditions. One of the key issues debated by conference participants was the definition and estimation of this baseline (as discussed in the next section).

- The prospective benefits of knowledge are assessed by peer reviews, as part of competitive and merit-based selection of portfolios and projects.

Methods for Estimating Prospective Benefits

The key issue in estimating prospective benefits is that, unlike retrospective benefits, they pertain to R&D investments that are ongoing or being *contemplated*, rather than already incurred. Past conditions (technical, economic, regulatory, and policy) are not directly relevant to prospective benefits because they do not include benefits that have been realized in the past. Realized benefits pertain only to retrospective benefits. *Future* conditions pertain to *both* retrospective and prospective benefits.

Many conference participants (excluding those in the knowledge workshop which did not discuss this topic) considered prospective benefits associated with the projected case as those associated with the base case or the most-likely scenario (although participants disagreed as to whether "most-likely" is an apt term for this scenario). This base case is sometimes referred to as the "business-as-usual" or "reference case" scenario. Many participants in the workshop on option value initially questioned the reasons for singling out a projected case, noting that it is simply one of any number of scenarios that could be realized in the future (their discussions are summarized under the Option Value section). The response of other participants was that DOE, including the Energy Information Administration (EIA), have traditionally devoted considerable attention to a base case in their forecasts and analyses. It was also noted that they have never attached any probabilities to this case.

Three important considerations in estimating prospective benefits were discussed:

- Determining the projected baseline conditions, on which new technologies are to be introduced,

- Projecting the market penetration and performance of a new technology, and

- Estimating the effect of the government's R&D program on the technology's development and use.

These issues took up most of the discussion in the workshop on cross-cutting issues in estimating prospective benefits, and are discussed below.[7]

<u>Projected Baseline</u>

To estimate the prospective benefits of R&D, a projected baseline must be established. This baseline is analogous to the counterfactual condition for retrospective estimates of the benefits of past programs. The workshop on prospective benefits had a technology focus and there was extensive discussion about the proper method for estimating the baseline. Many workshop participants described the baseline as the best “guesstimate” of what is likely to happen, without the technology under consideration (but *with* technological advance in other sectors).

Many workshop participants agreed that the projected baseline would:

- be an evolutionary one, with some progress in energy efficiency,

[7] The idea of a baseline did not seem relevant to many of those in the workshop on knowledge benefits, which had a basic science, rather than technology, orientation.

- include the most likely changes in the market and technology,
- include expectations about fuel prices,
- be based on *existing* laws and regulations.

There was considerable discussion about the merits and limitations of various, possibly complementary, methods for estimating the projected baseline such as:

- large-scale integrated models of energy markets,
- specialized models developed for the technology and sector under consideration,
- extrapolation of current trends, or
- interviews, polls, and case study of the specific R&D or technology under review.

Many workshop participants deemed EIA's large-scale integrated National Energy Modeling System (NEMS), and the assumptions underlying the Annual Energy Outlook's (AEO's) Reference Case, to be the best starting point for the baseline. They suggested that a good approach would one starting with NEMS, with the use of other models such as the MARKAL model, if NEMS were not suitable for the specific technologies under consideration.

It was discussed that different approaches might need to be used for different programs – there was not a "one size fits all" solution. But an important point made was that if different models are used for different R&D programs, then the models should be calibrated to the projected baseline conditions (e.g., as generated by NEMS) to assure consistency and comparability in results. Their respective assumptions should likewise be made as consistent as possible with those in the projected baseline (e.g., NEMS AEO Reference Case).

Several conference participants pointed out that the NEMS Reference Case includes, in a very general way, the effects of R&D programs underway at DOE. Thus, one should be careful to net out the assumed technical change in that technology sector when trying to assess the benefits of a specific technology against the EIA baseline, if that technology sector was already in the baseline.

Although many workshop participants favored the use of models for projecting a baseline and for estimating the effects of a government R&D program, several workshop participants questioned whether models are useful for these purposes. The concerns voiced against the use of models included the suggestion that the effects of an individual, relatively small R&D program are not reflected in large integrated or macro-models. Another concern was about how the models deal with interactions among ongoing R&D programs. Concerns were also expressed that the baseline definition was dealing with only individual programs and not the portfolio; and that the models were less useful for the longer term than for programs focused on the near-term – there was simply too much uncertainty in the longer term.

Many conference participants regarded that whichever method is used to project the baseline, the market under consideration for this baseline should be the one relevant to the technology under consideration. Baselines could be developed with interviews of independent, non-involved experts in the field of the R&D project, competitors, NGOs (non-government organizations), and others. This approach could be either an alternative or a complement to mathematical modeling techniques. In peer-review assessments of proposed R&D projects, there is an implicit baseline considered when rendering an expert judgement.

Many workshop participants also expressed the need to be transparent and clear in all assumptions and scenarios. Data limitations were raised as a common problem, as was the great cost of too much or too refined an analysis.

Market Penetration and Technical Performance

Many workshop participants favored EIA's NEMS model for projecting the market penetrations of new technologies. An advantage of NEMS is that it is an EIA model and is thus not associated with any R&D program in DOE. Also, the model accounts for interaction among competing new technologies.

As in the case of estimating a projected baseline, MARKAL or other models might be better suited for estimating market penetration of individual technologies because they might have greater detail about these technologies or be easier to modify to incorporate them. If such models are used to predict market penetrations, then several conference participants thought that they should be calibrated to the EIA NEMS AEO Reference Case.

As in the discussion on methods to use to estimate the projected baseline, workshop participants generally held one of two alternative positions on the more appropriate method to use: either integrated models, or person-to-person interactions that obtain information from those directly engaged in that line of business. The concerns raised about models, which were previously summarized, are pertinent to this discussion as well.

Two other approaches are commonly used to estimate market penetration: experts' judgements of the market penetration of the prospective technology (e.g., defining logistic curves for the diffusion and market adoption of the technology); and extrapolation of current trends, if the technology has already begun to penetrate the market. Neither of these approaches was extensively discussed during the workshop. But a general, widespread sentiment was expressed about the need for peer review, especially of subjectively determined projections.

Impact of the Government

Conference participants discussed how DOE funding could impact the path of an energy technology or practice. The impacts could be categorized as:

- the characteristics, scale and function of the technology (e.g., its emissions profile),

- acceleration of its commercialization and date of introduction in the market,

- the speed by which the technology gains market share after it is initially introduced, and
- the "final" level of market penetration, i.e., the maximum deployment or use of the technology.

Figure 8. Mary Beth Zimmerman of the Office of Energy Efficiency and Renewable Energy (EERE), DOE, briefs EERE Assistant Secretary David Garman as he prepares to give his keynote address that emphasized the importance of benefits estimates to his office's R&D planning process.

The NRC committee focused on the acceleration impact of government-sponsored technology R&D and defined the "5-year rule." This approximation assumes that the private sector would have initiated the same R&D at the same level of investment as the government, only five years later. Thus, the effect of the government program would be "only" to accelerate commercialization by five years. Several participants in the workshop on prospective benefits noted that the effect could be different from the 5-year acceleration assumed by the NRC, mentioning a broad array of possible impacts.

The view of many workshop participants was that the impact of the government varies on a case-by-case basis. They thought that an across-the-board "5-year rule" has advantages such as easy comparisons among R&D programs, but that it is probably incorrect. Many workshop participants stressed the importance of other factors influencing market penetration. They listed several factors to consider when evaluating both the impact of a government R&D program as well as the ultimate market penetration of the technology:

- The economics of the technology/product – both in terms of its scale (e.g., a $50 technology or product versus a $500 million technology or product) and its comparison to the next-best alternative.
- The percentage of government funding in the total R&D. Workshop participants cautioned that focusing on this ratio might result in an incentive to increase the amount of government funding to raise the benefits attributable to the government. This situation could be counter to other objectives, such as increasing private investment.

- The product development cycle – how long and what is involved in developing the product.
- The nature and fragmentation of the industry, its propensity to invest in R&D, and the nature of the competition (both foreign and domestic).
- The nature of the deployment and installed base of the product which the new technology is seeking to replace.
- Customers' non-economic attributes that affect the demand for the product.
- Whether the market that the product was entering is a competitive or highly regulated one.
- The likelihood and reasons for adoption by "early adopters" of technology.
- The nature of the market failure which justified a government role.
- The compatibility of the product with other products – does it enhance any other products?
- The riskiness of the research.
- The timing of when the benefits are projected to be realized.
- The precise actions of the government. Where is it sponsoring research – in private industries, universities, or national laboratories?
- Broad market conditions, policies, and regulations.
- The interaction of R&D with other government policies – tax credits for deployment, market transformation programs, etc.
- The stage of product development. If the technology is ten or more years from development and deployment, then some of these considerations were viewed as being much less important – e.g., the reasons for adoption by early adopters.

Some workshop participants noted that private industry is often extensively involved in technology innovation and development. Industry provides funding to the R&D itself and to the commercialization of the product. The workshop thus considered how to allocate some portion of the overall benefits of a technology to the government program itself, taking into account the previous list of factors. Since there are 100's if not 1000's of projects in the relevant DOE offices, most workshop participants thought that this analysis should be done on a program (and not on a project) basis.

Two generic cases were considered: 1) where the government involvement was necessary but not sufficient to develop the technology, and 2) where the government had an important effect but perhaps was not necessary for its development. In the first case, many workshop participants thought the government should get more credit for the technology development. Workshop participants stressed the need to identify between government and private sector activities at each stage in the development of the technology, in order to allocate its benefits between them.

The NRC committee, as part of its study, had tried to categorize the government's role in the most important energy technology developments of the past 20 years. For a retrospective assessment, the NRC committee categorized the government's impact as either dominant, influential, minimal or absent.

Looking prospectively, a similar *qualitative* assessment could be made about the significance of a government program:

- Dominant,
- Very important,
- Influential, or
- Minimal.

Several workshop participants cautioned that independent panels should be used to make this qualitative assessment, and that R&D programs should not all receive the same rating. Making distinctions among programs is important, they thought, despite the reluctance of some program managers to make them.

Several other approaches were seen as methods to allocate benefits *quantitatively*:

1) Based on percentage of government funding. The cautions noted previously about this approach were expressed again.

2) Using "traditional" market penetration models and comparing the effects with and without a government program.

3) Variations of the 5-year rule, which assumes that the impact of the government is to accelerate commercialization of technologies by five years.

   - If the time were 0 to 10 years, then the acceleration could be, say, between 4 to 5 years. If the time for deployment were 10 years or more, then the acceleration effect could be greater, say 7 to 10 years. This difference recognized that the longer the time horizon for deployment, the less the private sector would be interested in investing in R&D.

   - Estimate the acceleration of commercialization on a case by case basis. The nature of R&D and the technologies they are seeking to develop vary considerably – from compact fluorescent lighting, to biomass conversion, to fusion energy, to fourth-generation nuclear power technologies, to carbon sequestration. Uncertainties and incentives for private sector investment in research likewise vary. Thus, a variable-year rule could be used to estimate the acceleration of commercialization on a program-specific basis.

4) Methods which were useful in previous evaluations of programs. Whatever methods were successful for "backcasting" could be used to allocate benefits prospectively.

5) Government payback – return on investment to the government. In this approach, it is assumed that the government would be involved in technology

R&D in the form of loans or even equity investments. The government would receive a return on its investment, in addition to the public benefits that are presumably achieved by the technology. It was noted that NYSERDA (New York State Energy Research and Development Authority) is making such investments.

6) Random sampling of programs to obtain an idea of the importance of the government to the development and commercialization of the technology. This approach would involve field interviews and expert advice. The process could focus on only “big” programs if deemed appropriate.

7) If a qualitative rating is used, as previously described, then different percentages could be assigned to each qualitative rating to allocate numerical benefits to the government program. The percentages assigned should be the same across all programs for the same qualitative rating.

8) Peer review – forming independent panels with objective criteria to judge the importance and quality of a program. The four qualitative ratings discussed above could be used in this process.

For science programs, attribution of impacts to government programs is difficult because of the long and diffuse path from government-sponsored activities. It typically takes many years to apply the knowledge and knowledge capacity generated by those activities to the end outcomes. Expert judgments and trends in funding by sector are two indicators of government's contribution. Some participants in the workshop on knowledge benefits noted that the industry trend is to depend more on the federal government for basic research, as well as on outsourcing and collaboration. When the different contributions and products of research are not separable, however, several participants in the workshop on option value considered it impossible to calculate precisely the impact of the government program. One participant in that workshop suggested a production function approach to disentangle the approximate public and private sector contribution to the marginal increment of technology success.

Option Value

Definition of Option

Many of the participants in the workshop on option value agreed with the tenor of the following definition, though there was not agreement on precise wording:

> A real option is an asset (such as a technology) that allows a decision maker to utilize it to advantage in the future, and to learn about its possible prospects as the future unfolds.

Some workshop participants favored the definition developed in the NRC study **–** that options are technologies that are fully developed but for which existing economic or policy conditions are not favorable for commercialization. The extrapolation of this latter definition to prospective analysis would mean that the technology is developed intentionally *not* to enter the market if it turns out to be as currently projected. According to this definition, the technology would serve as "insurance" against unexpected developments in the future. Many of the real-options specialists in the workshop regarded this definition to be restrictive and that providing insurance is only one of the possible benefits of real options.

At least one conference participant pointed out that the motivation for many of DOE's programs is to provide technology options to address uncertain conditions in the future, such as oil-price shocks. Thus, from this perspective, providing option benefits is an integral part of DOE's mission.

Many of the real-options practitioners in the workshop initially thought that there should be no "projected base case" column in the matrix because the projected base case is simply one of many possible outcomes that might be realized in the future. These conference participants regarded the base case as having some probability of occurring, just as other possible future conditions have various probabilities of occurring.

Figure 9. Conference participants included (1st row, L to R) Susan Mohrman, University of Southern California; Herath Hermantha, University of Northern British Columbia; Kenneth Friedman, Office of Energy Assurance, DOE (then at the Office of Efficiency and Renewable Energy (EERE)); an unidentified participant; Phillip Tseng, EERE, DOE; (2nd row, L to R) Bob Hirsch, consultant (then at RAND); Jim Wolf, independent consultant; Susan Cozzens, Georgia Institute of Technology; and another unidentified participant.

However, it was pointed out that such a view is not consistent with current, well-ingrained program planning practices at DOE, which use a base case. Also, most people's limited familiarity with the real-option concept might lead them to discount any option value that is calculated. Thus, several workshop participants suggested a *gradual*, rather than comprehensive, introduction of the real-option concept into the methods which DOE uses to estimate its R&D benefits, as discussed below.

The measures or indicators of option value are the same as those discussed previously for prospective benefits (e.g., reduced energy costs measured in dollars). However, the methods for estimating option value differ from the discounted cash flow approach usually used.

Methods for Estimating Option Value

Several participants in the workshop on option value worked to outline a generic 4-step methodology for option valuation of technology R&D programs. They identified approaches for conducting each step.

1. Describe the uncertainty
    a. Use integrated energy-model scenarios and assign a probability to each scenario.
    b. Identify the source(s) underlying the uncertainty (technical performance, energy prices, environmental regulations, policies, market conditions).

2. Calculate outcomes
    a. Use the results of the scenarios developed in step 1.
    b. Develop a forecast using the underlying uncertainty characterizations.
    c. Use a simplified modeling approach.

3. Determine the decision actions
    a. Consider the following decision possibilities: (1) continue, (2) abandon, (3) expand, or (4) hold.

4. Do the expected-value calculation
    a. Carry out a standard net present value (NPV) calculation.
    b. Decide between a risk-neutral and a risk-adjusted approach (a contentious issue).

Several workshop participants pointed out that the type of data required for option valuation could be a significant deterrent to its full implementation. Given the desire among many workshop participants for a *gradual* introduction of this paradigm into DOE's planning process, at least one of the participants suggested that the following approach be considered in the near-term:

- Consider a scenario analysis and base it on common scenarios used DOE-wide.

- Create scenarios that are:
    - applicable to many and diverse DOE programs
    - widely accepted as unbiased
    - capture a wide range of future conditions
    - as few in number as possible.

- Use the NEMS AEO reference case (i.e., the projected base case) and others that vary across the economic, environmental, and security dimensions.

- To illustrate option value, calculate benefits under one or two scenarios in addition to the base case scenario.

- Note that the values based on a few alternative scenarios illustrate "optionality;" they do not provide an estimate of option value. A future improvement in this approach would be to assign probabilities to the scenarios. This would allow a crude calculation of the expected option value.

- DOE should support investigation of the probabilities (volatility) and correlation among key energy market drivers such as GDP, fuel prices, and environmental regulations. Probabilities of dramatic individual events, such as a nuclear moratorium or fusion breakthrough, should also be examined. If the range of probability estimates were to become generally accepted in the future, then these could form the basis for options analysis that would be preferable to the simple optionality approach suggested here.

Economic Benefits

Measures of Economic Benefits

Economic benefits are those primarily associated with a reduction in the costs of providing energy services and in the quantity of energy "consumed" to provide energy services. Economic benefits also include spillover and macroeconomic impacts on the economy. Spillover occurs from the use of the results of the R&D in applications other than in the technology(s) primarily being developed. The macroeconomic impact results from reduced cost to or greater productivity in other sectors of the economy, and from the associated multiplier effects.

Participants in the workshop that discussed economic benefits offered the following measures of economic benefits:

- value of net reduction in energy consumption, net of any additional costs (measured in dollars),
- reduced cost in providing a unit of energy service (dollars),
- value of spillover effects (dollars),
- macroeconomic impacts on the overall economy (including reduced energy consumption and reduced costs of energy), or
- value of increase in consumer surplus, which is the amount that consumers would be willing to pay minus what they actually pay for energy.

The first three economic measures are additive. Each of the last two measures overlaps with the first three measures. They are different measures of economic benefits.

Methods for Estimating Economic Benefits

Some DOE offices estimate economic benefits by:

- using engineering analysis to estimate the expected reduction in energy consumption for each new technology (i.e., its technical performance),
- projecting the annual market penetration and use of the technology,
- multiplying the per-unit energy consumption times the use of the technology, and then
- comparing the estimated energy consumption to the estimates of energy consumption from the technology(s), which the technology improved or replaced.

The workshop that had a session on economic benefits discussed other methods that could be used to estimate economic benefits:

- Use of a cost index to estimate the change in cost to energy consumers,
- Econometric analysis to estimate spillover and related macroeconomic impacts,
- Case studies,
- Technical and economic models,
- Detailed tracking (and extrapolation) of R&D outcomes, and
- Sampling techniques (statistical monitoring).

The cost index referred to above is essentially a ratio of expected consumer costs, with and without the new technology. It relies on assumed, or exogenously determined, adoption rates for the new technology. A model is used to estimate electricity generation costs and the associated external costs (e.g., from public health effects due to exposure to emitted pollutants). Monte Carlo simulation is used to incorporate uncertainty into the analysis.

Figure 10. Many participants were interested in the Office of Management and Budget's (OMB's) proposed criteria for assessing R&D investments, and how estimates of R&D benefits fit into these criteria. Among those listening to panelist Mark Weatherly of OMB were: (1st row, L to R) Sean McDonald, Daryl Brown, and Joe Roop all of Pacific Northwest National Laboratory; Chris Simpson, Office of the Chief Financial Officer, DOE; (2nd row, L to R) David Roessner, SRI International; Jack White, Association of State Energy Research and Technology Transfer Institutions; Bruce Tonn, University of Tennessee; and Don Jones, RCF economics consulting.

The econometric approach has been applied to estimate the benefits of industry-sponsored R&D in the manufacturing sector. The study, which was reported in the workshop, found that there were large spillover benefits of government R&D to other sectors and activities -- and that these were important and measurable. The study also found that there was some substitution of public R&D for private R&D. These econometric methods have thus far been applied to a whole sector (i.e., the manufacturing sector) rather than to individual R&D programs.

Environmental Benefits

Measures of Environmental Benefits

Environmental benefits are those associated with a reduction in damages to public health, or to the environment, from exposure to pollutants. The NRC study used the following measures:

- physical units of reduced emissions (measured in tons), or
- value of reduced pollutant emissions, for which the economics literature has estimated average $/ton values (measured in dollars, for criteria pollutants and carbon dioxide).

Other measures suggested at the conference were:

- environmental value of R&D, based on the value of information (which depends on the regulatory and policy situation),
- changes in an index of sustainable welfare.

Intensity measures were also offered (though it was recognized that these measures do not reflect the overall magnitude of the impacts or benefits):

- pollutant emissions per unit of output (e.g., reduction in tons per dollar output),
- energy use per unit of output (e.g., reduction in Btu's per dollar output).

Methods for Estimating Environmental Benefits

Some DOE offices estimate environmental benefits by:

- using engineering analysis to estimate the expected reduction in emissions of criteria pollutants and carbon dioxide for each new technology (e.g., in tons/MWh, tons per vehicle-miles traveled, tons per Btu, etc.),
- projecting the annual market penetration and use of the technology,
- multiplying the emissions rates of the technology times the use of the technology, and then
- comparing the estimated emissions to the estimates of emissions from the next-best technology(s), which the new technology is to replace.

Several workshop participants thought that, given the complexity of environmental impacts, indices are useful and appealing because they are relatively simple. One of the workshop panelists suggested an Index of Sustainable Economic Welfare (ISEW), defined as the sum of non-defense GNP plus human environmental capital formation, minus environmental degradation (the latter could be measured in terms of reduction in ecosystem services). [The relationships between prospective new technologies and the impacts of their deployment on changes in ISEW would need to be estimated.]

Several workshop participants also recognized a wide range of economic tools for valuing environmental benefits:

- Hedonic methods that identify relationships between economic assets such as property value and environmental attributes such as pollutant emissions,
- Contingent valuation which uses economic experiments to estimate individuals' willingness to pay to avoid specific types of damages to the environment or to human health, and
- Direct measures of market value such as loss in productivity or in the yields of agricultural crops, medical and health costs, and reductions in expenditures on recreation.

Security Benefits

Measures of Security Benefits

Participants in one of the four workshops discussed security benefits. Traditionally, energy security was related to oil consumption in a market in which a cartel has monopoly power. More recently, energy security refers to vulnerabilities of energy infrastructure and systems to terrorist and other disruptive events.

One presentation offered a definition for "energy security" to be "energy being available when needed at a predictable price." [This definition applies to near-term availability and prices, and not to the ability to predict energy prices many years into the future.]

Workshop participants listed several major types and measures of security benefits, and grouped them into three categories (suggested units of measurement are in parentheses):

a) Prevention or reduced probability of disruption, security breach, or system failure, and their associated costs --

- Reduced net oil import costs (measured in $)
- Reduced expected damages ($) and injuries (pubic health and safety)
- Reduced environmental costs that result from possible terrorist activities that might damage the natural environment (reduced environmental impact)
- Lower liability costs ($)
- Lower insurance costs ($)
- More predictable energy prices (accuracy of predicted prices)
- Reduced costs for military presence and activities in the Middle East ($)
- Reduced costs of protecting domestic energy infrastructure ($).

Management of response, given that an event has occurred --

- Lower macroeconomic disruption costs when there are price spikes due to major unanticipated disruptions in energy supply ($)
- Lower cost of emergency management ($).

b) Recovery and repair --

- Increased speed of response and recovery (engineering estimates of the time it would take to restore energy services)
- Reduced cost of recovery and repair after a disaster occurs ($).

Methods for Estimating Security Benefits

Several offices in DOE currently estimate the number of barrels of reduced oil consumption, as a result of substitution by other energy sources such as renewable energy (e.g, ethanol from biomass as a substitute for gasoline from crude oil). The estimates are based on the projected market penetration of these alternative sources, and on their technical efficiencies relative to conventional technologies.

One of the presentations in this workshop summarized a synthesis of the literature on oil security and its benefits. In this literature, estimates of the benefits of oil security are expressed in units of $/barrel. This parameter could be applied to estimates of the barrels of reduced oil consumption to calculate energy security benefits in economic terms.

A few workshop participants noted that a complex simulation model would be very useful to assess the impacts of disruptions, and thus the benefits of R&D that mitigates them. Such a model would simulate the integrated operation electric power, telecommunication, transportation, emergency service, and other government service infrastructures.

However, without such models, some workshop participants suggested that some of the following indicators of energy security benefits could be used:

<u>Supply and Demand Conditions</u>

- Energy import levels (both in quantity and dollars)
- Diversity of delivery channels
- Diversity of supply sources
- Degree of monopoly/cartel power (measured by OPEC market share)
- Funds sent to potentially unfriendly nations
- Insurance rates/costs.

<u>System Flexibility and Sensitivity Measures</u>

- Price elasticity of world demand for various fuels
- Price elasticity of U.S. demand for various fuels
- Substitutability: dual-fuel electric generating capacity
- Fuel stocks (oil and gas)

- Macroeconomic sensitivity to energy shocks (perhaps measured econometrically).

Reliability/Volatility Measures

- Electric power interruption frequency and duration (outages, supply disruptions)
- Other measures of power grid reliability (power quality, brownouts, etc.)
- Capacity to meet peak electricity demands
- Investor confidence, PE (price-earnings) ratios
- Price volatility measures for various fuels
- Transmission/transportation reliability indicators
- Survey responses of infrastructure owners and users.

Knowledge Benefits

Measures of Knowledge Benefits

One of the presentations in the workshop on knowledge benefits suggested that science is a cumulative cascading process that involves the generation and transmission of knowledge. The perspective of many of the workshop participants was that government funds science for two reasons: knowledge creation and knowledge as a foundation for application (i.e., developing competencies such as human capital). Thus, although the participants in the workshop noted that knowledge has many meanings, many participants regarded knowledge as both an ultimate outcome as well as an "enabler" of other benefits -- an intermediate outcome or even an output of applied R&D programs.

The group also viewed knowledge benefits within the broader criteria that COSEPUP (the Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine) recommended for GPRA assessment. The workshop also considered knowledge benefits in the context of OMB's recommended criteria for investment in basic research:

- Quality (of the research)
- Relevance
- Performance (in terms of both management and results).

Given the conference's focus on benefits as being outcome measure of performance, we concentrate on synthesizing the workshop group's discussions about knowledge within the performance-outcomes part of the framework (i.e., the blue and blue-striped portion in Figure 6).

The group discussed adapting a generic model for the knowledge-related outputs and outcomes of research, first developed for the Basic Energy Sciences "research value mapping" project in 1994, and recalled by one of the workshop speakers. Several in the group developed the following depiction of knowledge outputs, outcomes and benefits, given in Figure 11.

Research investment leads to:

→ Information

which when used has the following benefits:

→ New ideas
→ Research tools
→ Human Capital
→ Communities of practice
→ Application opportunities and transitions

which lead to

→ Enhanced capacity for research and agility
→ Realized benefits in markets and missions

Figure 11. Development of Knowledge Outputs and Outcomes

Participants in workshops, other than the one focusing on knowledge benefits, did not have an opportunity to discuss knowledge benefits extensively. However, some participants in these other workshops noted, as did some participants in the knowledge-benefits workshop, that knowledge and ideas, research tools, human capital, communities of practice and spin-offs could result from applied R&D, just as they could from basic research (though they did not use these exact terms).

Some participants in one of these other workshops suggested that a measure of the effectiveness of R&D is reduction in uncertainty, which can also be considered acquisition of knowledge. This idea reflects the suggestion of the knowledge-workshop participants that knowledge benefits underpin the benefits of the applied research and technology programs; that is, they are a third dimension. Some participants in the knowledge-benefits workshop indicated that they would like OMB to place a higher value on knowledge-based capacity considerations when evaluating the prospective benefits of R&D programs. They recognized, however, the need to address the challenge of "setting the bar higher" in defining such benefits.

Methods for Estimating Knowledge Benefits

The participants in the workshop on knowledge benefits suggested several indicators for benefits of knowledge, listed in Table 2.

Table 2. Examples of Indicators of Knowledge Benefits

Type of Knowledge Benefit	**Example of Indicator**
Scientific merit	Quality and relevance (prospects and accomplishments) as judged by peers
New ideas	Research questions answered. Program milestones attained
Research tools	Operability of scientific facilities. Expert reviews of the construction of research facilities.
Human capital	Number of graduate students trained
Communities of practice	Connectivity index or measure
Transitions and spin-offs	Removed barriers, intellectual property

One speaker in the workshop on knowledge benefits presented the many ways in which bibliometric techniques can be used in the assessment of research. Bibliometrics could be used prospectively for human capital issues and to trace networks. It could also be used as an indicator of vitality, and of where one might need to make investments in R&D. By investigating papers that cite other papers, the organization can assess the knowledge incoming and outgoing from an organization. By considering the percentages of top-cited papers, one has an indicator of their quality and a value distribution across a portfolio. In addition, by considering patents that cite papers and patent portfolios, one can do a network analysis of the "innovation process." Tracking individual researchers' names through the patent system would also be valuable, for example to show the need for expertise.

Similarly, other kinds of prospective analysis can lead to theories of how inputs lead to outputs, that is, theories about what goes on inside the "black box" process of managing and doing R&D. Many workshop participants felt that it is important to describe this process. That information would help understand the use of management as a decision tool. Black-box answers "show what managers do that makes programs work." These studies could also use a "logic model" to attribute or link program activities to knowledge value communities, or communities of practice, which were viewed by many workshop participants as being the sort of outcomes that are important.

Another workshop speaker spoke from 30 years experience managing research at Dupont and participating in the Industrial Research Institute's Research on Research Committee. He also spoke of knowledge as a third dimension in all R&D investment decisions and of the importance of managing the black box. He pointed out that within the non-linear innovation system that includes inputs, processes and outcomes, different stakeholders are interested in different metrics. He listed different types of benefits estimating techniques: net present value, rules of thumb, database of assessments, studies by independent analysts, value of intellectual property and orphan patents, and financial analysts' estimates of value.

This speaker also addressed the question of what to do about assessing the benefits of basic research and pointed to ideas on radical innovation, the knowledge-drivers-of-the-future diagram, and strategy tables. According to some workshop participants, a possible benchmark for DOE to use when thinking about risk is a study on the success rate of new products that showed that it took 3,000 new ideas to get 300 submitted ideas, and eventually end up with one new commercial success. Thus, these conference participants stressed that an organization needs a steady pipeline of R&D.

The nature of research is experimentation. Therefore, some conference participants noted that finding out what does or doesn't work has value. One participant suggested that knowledge benefit is gained from what is learned from a "failed" program that reduces the uncertainty about what would be a "successful" tack of R&D; and suggested that the order of magnitude of this benefit could be quantified. This notion of reducing uncertainty and risk by investment is central to the real option methods discussed in that workshop. Thus, it might be worth investigating whether some of the quantitative tools discussed in that workshop could be relevant in this context as well.

Data Sources

DOE participants at the conference emphasized that data availability must be a major factor in considering the alternative measures to use and the methods for estimating them. Conference participants identified various general sources of data:

- Publicly available data such as those from EIA and the Department of Commerce,
- Data from private sources which are reliable, relatively inexpensive, and available on a continuing long-term basis,
- Polls and surveys, both formal and informal, to assess consumer confidence in regard to security issues, baseline conditions (e.g, what would happen with and without the technology), and the impacts of the government program (e.g., in a prospective sense, is the impact of the program likely to be dominant, very important, influential, or minimal),
- Engineering and expert judgement (e.g., key technical performance parameters, peer review of basic research programs), and
- Outputs or predictions of other models (e.g, from EIA or Department of Commerce).

When it is necessary to use experts' subjective judgements to peer review the quality of basic research or to estimate key parameters, such as the market penetration of a technology, many conference participants stressed the importance of impartiality. It was noted, however, that it is difficult to have complete impartiality and objectivity in such reviews because the people who are most knowledgeable about a technology are involved directly in its development or are working under contract to DOE in a related program(s).

Use of Estimated Benefits in Program Planning and Evaluation

Discussion in one of the workshops raised the question of "what it is that OMB wants to know." Retrospective assessment answers the question "was it worth it" -- as in the NRC study. Some participants in that workshop suggested that OMB would like the R&D programs to use criteria, such as estimated benefits, as a planning tool, not only as a retrospective assessment tool. DOE programs could use these criteria to make decisions before their proposed budget goes to OMB, using the criteria to differentiate among different kinds of programs and their prospective benefits.

Figure 12. Prof. Joseph Wholey, University of Southern California, gave a light-hearted keynote address, yet one with an important message.

Several conference participants highlighted the importance of portfolio management. The workshop on option value discussed the need to cut across DOE stovepipes to assess the benefits of R&D portfolios. Decisions to terminate a program were regarded by many as being as important to consider as those to initiate or to continue one. Many conference participants also thought it important to view individual programs as part of a broader energy R&D portfolio, and to regard estimates of benefits as but one criterion to consider in R&D investment decisions. Other criteria mentioned in the workshop were the R&D's time frame, program cost, and technical risk. Workshop participants liked the use of visual representations of portfolio analyses that depict the interplay and trade-off among decision criteria.

One speaker showed a portfolio tool, the familiarity matrix, developed at MIT's Sloan School. The matrix considers the interdependence between the newness of a technology with the newness of the market to the firm. An organization can use it to help manage risk. Pursuing a new technology in a new market would be in the “suicide square" of the MIT familiarity matrix, for example. Several conferees suggested that it is important to remember that order of magnitude estimates are sufficient at first.

Some conference participants emphasized the importance of setting goals for the programs, quantitative to the extent possible, in terms of their various benefits (e.g., reduced carbon). Some R&D programs would presumably lead to certain types of benefits, but not to others. Some programs would in retrospect be more successful than others, depending on what happens in terms of future economic, geopolitical, regulatory, and policy developments. By their comments, some conference participants appeared to view the portfolio approach as one of *efficient diversification* of R&D options to account for:

- national needs and priorities for foundational, basic research,
- synergistic as well as the counterproductive aspects of jointly developing various technologies, and synergies among basic and applied research efforts,
- competing and supportive aspects of various technologies in the market, and
- uncertainty about future conditions, as well as about the effectiveness of the R&D and the technical performance of the technology and its competitors.

Several participants pointed out the importance of evaluating past performance -- meeting interim milestones that were set -- as part of the planning process. Some conference participants noted that the "alternative format," as provided for under GPRA, could be used fruitfully to report on intermediate outcomes. R&D programs can affect intermediate outcomes more directly than end outcomes such as a technology's economic benefits. The waiver an agency receives to use the alternative format allows it to use qualitative statements of performance objectives. The National Science Foundation uses this format, for example.

According to several conference participants, DOE should assure that the tools used for program decision making recognize option value. Some conference participants noted that options-thinking leads to a different method of planning, so that in addition to being a tool for estimating benefits, options consideration is also a more general management tool.

Scoring systems that use various scales can include optionality considerations and can be applied to many programs. The scales could cover the following criteria:

- Potential impact of the technology,
- Uncertainty and potential for learning, and
- Flexibility in developing and implementing the technology.

For example, the flexibility scale might be built around the following concepts:

- High flexibility
  - Technology creates value in many different scenarios,
  - Much of the research is applicable to many other technologies,
  - Research investment is *not* lumpy, that is investment can be made in stages. For example a program that requires $10 million/year over five years is more flexible than a program that requires $50 million of immediate investment.

- Low flexibility
  - Technology creates value in only a single scenario,
  - Research is specialized and contributes to a single technology,
  - One large lump sum investment is required.

Application of this type of scoring tool would require a peer review to assure a relevant scoring process.

Many participants agreed on the need to have a uniform framework that would be used across all relevant DOE offices, and a consistent set of assumptions and projected baseline. Many participants also appeared to agree on the need to continually improve the methods for estimating the various types of benefits and to do pilot testing of these methods on selected programs before implementing them office-wide.

Finally, some conference participants argued for more common sense in R&D program planning and evaluation. They regarded the use of complicated frameworks and methodologies as overreaching their current capabilities to accurately predict the benefits of R&D.

In any event, it was recognized that "to talk about the bull is not the same thing as being in the bullring." This is true both of talking about a benefits framework as opposed to actually building and implementing one, and true of talking about the R&D planning process as opposed to actually doing it.