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IDEAS ON A FRAMEWORK AND METHODS FOR ESTIMATING THE BENEFITS OF GOVERNMENT-SPONSORED ENERGY R&D

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SUMMARY

This white paper presents a starting point for discussions at the conference on "Estimating the Benefits of Government-Sponsored Energy R&D." The specific objectives of this conference are to identify major streams of thought on:

(a) a useful methodological framework for identifying the benefits of government-sponsored energy R&D; and

(b) practical approaches for developing improvements to current methods of estimating the benefits of energy resource and science R&D, which might be used to enhance the performance-based management of these programs under the Government Performance and Results Act of 1993 (GPRA).

The contents of this paper should *not* be interpreted as recommendations to any government agency. Rather, the ideas are intended to stimulate discussion at the conference.

Background and Motivation for the Conference

The motivation for this conference is the priority that the energy resources and science offices in the U.S. Department of Energy (DOE) are giving to measuring and assessing the performance of their R&D programs. Under GPRA, DOE and other federal agencies are required to report annually on their programs' plans and performance. Furthermore, President George W. Bush and the U.S. Congress are placing great emphasis on performance-based assessments in the funding of federal programs.

Estimates of program benefits are one part of the performance requirements established by GPRA and implemented throughout the federal government. GPRA addresses both expected performance and retrospective evaluation at all levels of government activity – project, program, office, agency—and in all time frames—monthly and quarterly execution, annual and multi-year milestones, final outputs, and resulting market impacts or benefits. This conference focuses on ways of improving our ability to estimate the ultimate benefits that result from the outputs of energy R&D programs. The conference does not directly address other GPRA requirements.

Estimating the benefits of R&D programs is challenging because of the very long time frames required for basic and applied research, the process of introducing the resulting product into the market, and the lifetime of investments made in the product. In some cases, over half a decade might be required to examine the full impacts of a line of research. In addition, the results of a research portfolio are not simply the sums of the results of its individual parts. Because benefits are often the result of multiple areas of effort, this conference focuses on benefits at the program level and above, rather than on performance related to individual research projects.

The level of benefits depends both on the success of the research effort itself (outputs) and on changes in the various “external factors” – market or policy conditions – that affect the market penetration and market shares of these new technologies. Another challenge is the implementation of a methodological framework in a sufficiently transparent way that the relative contribution of the R&D, and of the external assumptions, on projected benefits is clear, and that the different reasons why projected benefits are (or are not) realized can be documented.

A government agency's research portfolio can affect literally thousands of products throughout the economy over several decades. It is essential to carefully consider the value of this research, both retrospectively and prospectively. It is also important to undertake such studies of the benefits of R&D -- for the purposes of GPRA and program planning -- in ways that are practical and cost-effective.

Benefits Framework Developed by National Research Council Study

There are many ways of addressing the stated objectives of the conference. However, the recent study done by the National Research Council's (NRC) Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy provides an important context for this conference.[1] The NRC study developed and implemented a methodological framework to estimate the retrospective benefits of individual energy efficiency and fossil energy R&D programs in DOE.

Thus, the framework that we suggest as a starting point for discussions at the conference is *adapted* from the one developed in the NRC study. The NRC committee used a matrix with three rows and three columns to represent the benefits framework it developed. Three basic types of impacts are listed along one dimension of the matrix (i.e., the rows): economic, environmental, and security. The other dimension of the matrix (i.e., the columns) reflects the degree of commercialization, certainty, and specific use of the benefits. Along this dimension, the benefits are classified as being realized, options, or knowledge. Each of these categories of benefits is described below.

- Economic Benefits: Measured by the change in the market value of goods and services that are produced under “normal” economic conditions resulting from the introduction of a technology stemming from DOE research. The benefit is measured net of all public and private costs, and can typically be reflected in changes in the level of goods and services produced or in their market prices. The NRC considered the program costs -- the costs borne by DOE and private industry in conducting the R&D -- as well as any incremental costs of the technology borne by the end-user or consumer.

- Environmental Benefits: Based on changes in the quality of the environment because of DOE research. The benefit is typically not measured directly by changes in market prices, but rather by some measure of the value individuals in society are willing to place on changes in the quality of the environment and improved public health. In cases where the research reduces the costs of complying with environmental regulations, the benefit takes the form of lower compliance costs rather than improved environmental conditions.

- Security Benefits: Measured by changes in the probability or severity of abnormal energy-related events that would adversely impact the overall economy, public safety, or the

[1] 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. The report was requested by the Appropriations Committee of the U.S. House of Representatives.

environment. Traditionally, this was primarily a concern about volatile oil markets. Recently, there is increased concern about the reliability and security of the energy supply infrastructure.

The NRC recognized that R&D might lead to benefits even when a technology developed by that R&D does not enter the market immediately or to a significant degree at all. This lack of commercial use might be due to changes in the forecasted economic or policy conditions, or to technical shortcomings. To account for this uncertainty, and to reflect the different degrees of technology development in a retrospective assessment, the NRC established three categories:

- Realized Benefits: These economic, environmental or security benefits have been realized by the current time, or are almost certain to be realized in the near future, as a result of the research effort leading to the development of commercially-attractive technologies. Often, these results are an acceleration of technologies that would have otherwise been commercially available at a later date. In other cases, they might represent new technologies or changes in product attributes that the private sector would not have produced on its own. The NRC included all lifecycle benefits of the units of the evaluated technologies that were projected to be installed by the year 2005.

- Option Benefits: This category covered technologies that are fully developed but for which existing economic or policy conditions are not likely to be favorable for commercialization. To be considered an option by the NRC committee, the technologies needed to be favorable for commercialization under some credible or plausible circumstances. For example, carbon sequestration technologies are options whose value might be realized if new regulations or trading of carbon emission permits take effect.

- Knowledge Benefits: R&D, whether successful or not, typically produces knowledge. The generation of scientific knowledge is a key part of DOE's mission. The NRC considered knowledge benefits to be scientific knowledge and useful technological concepts that have not yet been incorporated into commercialized results from the R&D program, but that hold promise for future use or that are useful in unintended applications. These benefits are in addition to those accounted for in the other areas of realized and option benefits. Knowledge benefits tend to be the earliest benefits from the R&D process.

Benefits Framework Adapted from the NRC Study

As we turn from the *retrospective* context of the NRC study, to the *prospective* one needed for program planning and GRPA, we suggest that the NRC benefits framework could be adapted or expanded in the following ways:

- The concept of realized benefits in the retrospective context could be augmented with a projection of *expected prospective benefits* under the most likely scenario. This change would effectively add one column to the benefits matrix to represent these expected prospective benefits.

- The definition of the baseline condition, against which a new technology or new science is "added" as a result of R&D, could be expanded from a strictly retrospective context to include the prospective situation.

- The impact of a government R&D program, on technologies developed in part by the private sector, could be estimated prospectively.

- The definition of options could be expanded to include not only the retrospective definition (that options are technologies that are fully developed but for which existing economic or policy conditions are not likely to be favorable for commercialization), but also the prospective context of R&D investments under uncertainty.

- Retrospective indicators of the knowledge generated by past R&D could somehow be expanded to consider the potential knowledge from ongoing and planned science projects.

- Methods for estimating some of the security, economic, and environmental impacts of R&D programs, which the NRC committee did not have an opportunity to develop, could be re-analyzed, especially in light of the terrorist events of "September 11."

- Data and data management requirements for prospective analyses could be assessed, including whether the requisite data are available and affordable. Also, consideration could be given to whether the methods can be implemented without having to rely on unverifiable assumptions, which would limit the credibility of the resulting estimates.

- Within a GPRA and program management context, greater attention could be given to developing methods for program planning and decision making that *use* the estimates of the benefits of R&D programs, a point made by the NRC study as well.

This white paper expands on each of points above to provide a basis for discussions at the conference. Each point is discussed further in the rest of this summary.

Expanded Benefits Framework to Accommodate the Need for Prospective Analysis

Pursuant to its charge, the NRC study developed its framework to assess retrospective benefits on a case-study basis. In order to adapt the framework to GPRA purposes, we suggest a framework that builds on the NRC's 3 x 3 matrix. GPRA requires that performance statements be tracked from pre-program planning through post-program evaluation. As a result, the benefits framework is extended to address *prospective* benefits in a way that allows the benefit estimates to be tracked over time. This requires the addition of a fourth column in the matrix. The need to undertake prospective analysis also requires consideration of the ways in which benefits develop as R&D matures, and considerations of the differences between retrospective and prospective information. In the following figure, we have modified the NRC matrix by adding the "prospective" column. It was not part of the NRC framework because that study considered only retrospective benefits.

Modification of National Research Council Committee's Framework
For Identifying Benefits of Energy R&D

	Realized Retrospective	Expected Prospective	Option	Knowledge
Economic				
Environmental				
Security				

Once a framework is established, practical means are required for estimating the benefits represented by each cell. Populating each of these twelve cells with estimates is a daunting task, especially because many of the cells represent cutting-edge areas of valuation theory, are areas of controversy in the literature, or require data that are either unavailable or extremely costly to collect and maintain. We suggest a framework in which benefits can be described in ways as closely related to the research efforts as possible (e.g., physical units of energy produced or saved), with augmentation, where possible, with transparent valuation into dollars. We also recognize that benefits that are not directly measurable even in physical units must sometimes be represented by proxy or index information.

Expected Prospective Benefits

We suggest that the expected prospective benefits could be defined as those expected from future deployment of a technology developed as a result of R&D, under the projected baseline set of future market and policy conditions, compared to the expected conditions under the same projected baseline, without the technology. Thus, estimation of expected prospective benefits requires a baseline characterization of future energy markets without the government research, and an estimation of how baseline markets will react to the new or accelerated technology, including its expected market penetration. These expected prospective benefits could be economic, environmental or security-enhancing; and they could be calculated over some pre-determined time horizon, such as the next twenty years. Longer time frames might be required to capture the full benefits of basic research or technologies requiring fundamental changes in energy infrastructure.

This definition of expected prospective benefits is somewhat analogous to that used by the NRC committee for retrospective benefits in that the benefits of the technology are net of those of the next-best alternative. In the prospective case, the next-best alternative is reflected in the reference baseline, which includes technical improvement. The question of defining the projected baseline is addressed in Section 6.1.2.

The projected market penetration of a new technology is a key parameter that greatly affects the magnitude of its expected prospective benefits. In this regard, we suggest that it could be preferable to characterize the attributes of the technology and to use a model to project how well the technology will do in the market, than to simply assume a certain level of market penetration after some number of years.

We further suggest that the model used for this purpose be calibrated, to extent possible, to the same one used for the projected baseline. Then, the Reference Case run of that model would be the projected baseline, *without* the technology in question. A run of the same model augmented with a simple representation of the technical performance and supply (curve) of the technology in question, could be the case *with* the R&D program. Where a different model is better suited to analyzing the specific technology than the one used for the baseline, then the other model can be calibrated to the baseline. The difference between the economic, environmental and security conditions in these two runs of the model would be the expected prospective benefits of the technology.

We suggest that the results of these calculations, which provide projections of annual net benefits, could be reported in both of the following ways:

- Total net benefits, in five-year intervals over the next twenty years (for example), in real dollars, with no time discounting, *and*

- Net present value, in which the estimated future benefits and costs over the operating life of equipment deployed are discounted.

Projected Baseline

Defining a baseline is an exercise in identifying the next-best alternative. Expected improvements in technology, that can occur regardless of whether a DOE program exists, must be accounted for.

For the prospective case, we suggest that the "reference case" of a DOE forecasting model such as the National Energy Modeling System (NEMS) could be considered for defining the projected baseline. If this model is inadequate for this purpose, then we suggest the use of alternative models that have better descriptions of the technology or markets under consideration. Alternative models that could be used include MARKAL and consumer choice models that identify the marginal reference-case choices of technologies (i.e., the next-best alternative). If such models are used, then we suggest that they could be calibrated to the more important assumptions in the NEMS reference case to the extent possible.

In the retrospective case, the issue is one of defining the counterfactual past condition. In either case, engineering judgement might be required to "back out" the technology in question, which might implicitly already be included in the reference case assumptions.

Impact of the Government

The 5-Year Rule adopted by the NRC study as a "conservative" means of valuing benefits (NRC, p. 18) assumes that the private sector would lag DOE by five years, with the same level of R&D and the same outcomes, if DOE had not itself invested. We suggest that this rule could be generalized and that the impact of a government R&D program could be represented as a change in the timing of the benefits of the technology developed from that program. We further suggest that the specific time lag could be determined on a program by program basis. Just as, for example, supply curves that describe the quantity of energy services available at different prices are different for different technologies, government R&D programs will reduce the time it takes for technologies to reach market by different amounts of time. For prospective estimates of benefits, the technology improvements in the reference case implicitly define the time frame for commercialization without the government R&D program.

For technologies that are developed to the extent that they are fairly close to commercialization, such many of those funded in the past by the National Institute of Standards and Technology's (NIST's) Advanced Technology Program (ATP), the median lag was found to be about 3 years. The lag ranges from about 1 year to an infinite number of years (i.e., the firm would never have carried out the R&D without support from ATP).

The magnitude of the lag will affect the magnitude of the calculated benefits associated with public R&D programs, and it would be informative to compare the relative values of potential R&D efforts when different rates of accelerated commercialization are assumed. Thus, we suggest that lags could be assessed on a program-by-program basis. If the technologies under development are on the verge of commercialization, then we suggest that a three- to five-year lag could be appropriate. For new programs and R&D initiatives in their early stages, the lag might be ten years or more. Many programs would have infinite lags, i.e., the private sector would never undertake the R&D.

Note that whatever lag is used, it represents the impact or contribution of the government program in prospective estimates of benefits. Then there would be no need to reduce the benefits beyond this time-lag adjustment. Alternative approaches are discussed in the paper.

Option Benefits

The state of the future projected in the "reference case" is (in theory) the most likely, but certainly not the only possible future. We suggest expanding the NRC study's concept of option technologies, which was defined in a retrospective context, to include the prospective situation.

In general, options provide discretionary choices to deal with deviations from planned scenarios. We suggest that a real options approach could be used for plausible energy scenarios other than the reference case scenario used for estimating the expected prospective benefits.

In a prospective sense, there could be option value to R&D on technologies that are not being developed *primarily* to enter the market under the most likely conditions, but that would provide economically viable solutions under alternative plausible conditions. These plausible futures are generally of energy, environmental, security or other policy concern. Physical or intellectual assets (not necessary fully developed technologies as defined in the NRC study) that might be deployed in the future (not just under improbable conditions) may also contain significant option value. In this sense, options provide insurance in the face of market uncertainties, yet retain the ability to capture the upside benefits should improbably scenarios be realized.

In a retrospective sense, technologies that are already developed, but that are unlikely to be commercialized under current or anticipated market conditions, may yet contain option value. This value is derived from the uncertainty surrounding future market conditions. These technologies might have been developed to enter the market but did not do so because of changes in conditions -- the technologies remain available for the market in the future should conditions change to make them commercially viable. For example, carbon sequestration technologies could be options whose value might be realized if new regulations or trading of carbon emission permits take effect.

Often, a research line is pursued because it has limited, but important, expected benefits through niche market applications, but would be expected to have much wider market applications under some alternative futures, e.g., an oil disruption. While option values can persist after the research is completed (often referred to as backstop or shelf technologies), the value of the option will change as we move further into the future and more certain about whether the technology application is economically viable.

R&D can be considered as investments in options that provide opportunities to realize benefits, in the event of alternative future events. In addition to the option to commercialize, R&D investments contain a host of other investment timing options. At each stage, as new information becomes available about the probabilities of different outcomes, choices can be made regarding continuation of the research, abandoning the research, mothballing the research, etc.

To calculate option values, input data are typically required for:

- Amount of the R&D investment, for which the corresponding value of the option is to be calculated, as well as some estimate of the technology outcomes that result from the R&D;
- Degree of uncertainty about the costs to provide energy services using the technology in question, as a function of R&D;
- Degree of uncertainty about the costs to provide energy services using competing technologies, i.e., degree of uncertainty of the projected baseline prices; and
- Degree of technical uncertainty (risk) about the cost of bringing the technology to market.

Developing these input data is a real challenge, especially when done for the first time. The uncertainties can be expressed "continuously" using probability density functions, or "discretely" using a few scenarios. Much of the real options literature uses continuous representations of uncertainty over the range of relevant future market factors. On the other hand, scenario analysis is frequently more intuitively appealing. It is a well-established approach to planning that allows individuals to assign their own views about the probabilities associated with various scenarios.

Knowledge Benefits

We suggest that bibliometric methods could be used to develop indicators of the value of the knowledge associated with research programs. For retrospective analysis, we suggest that indicators could be developed that reflect the linkages between science and innovation, such as:

- Current Impact Index. This index considers how frequently other patents are cited in patents granted in a current year.
- Science linkage. This method counts the number of times a patent cites scientific papers or similar research publications. This measure indicates how strongly a patent has relied on fundamental scientific research.
- Technology-cycle time. This index is the median age of patents cited on the front page of a U.S. patent document. This measure indicates the speed of innovation in a company or industry.

Similar analysis could be done with R&D 100 Awards.

For prospective analysis, research might first be done on whether results from retrospective studies could be used to develop simple models that describe the linkages between the outputs of science programs and their ultimate outcomes. Then, statistical relationships might be developed for these linkages, which might in turn be used for prospective assessments.

We suggest that peer-review methods could be adapted and used as the primary method for assessing the prospective benefits of scientific programs. An example might be the use of Delphi processes to develop assessments of the prospective knowledge-related benefits of various science programs. GPRA-like projections are generally much different from typical technical peer reviews, though, so that peer reviews for the purpose of GPRA-related requirements would need to be crafted to address these needs.

Security Benefits

We suggest that security benefits related to oil use and imports, the vulnerability of energy infrastructure and systems, and the reliability of electric power supply could be included among the possible benefits of energy R&D. This is a broader definition than what the NRC study addressed. In particular, we suggest that the definition of security benefits could be broadened to include those that reduce oil dependence and its costs, not only those associated with abnormal events; and those that improve electric power reliability, including that under "normal" operations.

Oil Security: Oil security measures are well developed in the literature. They can be expressed in barrels of reduced oil consumption or reductions in oil intensity (oil used per dollar of GDP). The energy security literature has also estimated values in dollars per barrel reduction in oil consumption.

Infrastructure and Systems: We suggest that benefits of energy infrastructure and system security could be estimated using probabilistic risk analyses to estimate the impacts of the technologies on the following:

(a) Reduced cost of outage or disruption to users,

(b) Reduced cost of providing a given, desirable level of security (e.g., cost of security personnel and equipment),

(c) Reduced impact on an industry and on the economy region- or nationwide (e.g., estimated using economic input-output models).

Electric Power Reliability: We suggest that the benefits of electric power reliability could be valued by taking into account:

(a) "Real-time energy value" – replacing the measures of energy savings and their financial value (Btu's and Btu’s times *average* price, respectively), which are currently used, with a measure of financial savings that accounts for energy savings (and increases) and the *different* electricity rates at different times of the day and year;

(b) “Reduced outage costs” – the financial value of reliability as measured by the estimated reduction in customers’ outage costs; and

(c) Reduced costs of providing required level of reliability, including reduced costs of providing alternative means of reliability.

Economic Benefits

We suggest that, in addition to the economic benefits associated with energy savings, other economic benefits could be included:

(a) Consumer benefits other than energy savings, such as increased productivity, which could be estimated using engineering analysis, survey, and experimental economic methods; and

(b) Macroeconomic benefits that will result from spillover effects, and which could be estimated using econometric methods.

The NRC study did not address these benefits in the same detail as it did the economic benefits of energy savings.

Environmental Benefits

We suggest that environmental benefits could be reported based on physical units of reduction, and valued using $/ton values for criteria pollutants and for carbon dioxide, as developed in the extensive literature on these subjects. This literature advocates using estimates of the damages from the pollutants as measures of their (deleterious) value, as opposed to the costs of controlling these emissions. Sensitivity analyses could be done to account for the significant range of estimates of these values, particularly since the values are sensitive to the size and geographic distribution of the population exposed to pollutants.

We also suggest that a separate index could be used for ecosystem impacts. This index could be an estimate of the value of increased "services" provided by ecological systems. Values expressed in $/hectares per year might be used for open-ocean, coastal, forest, grass/rangeland, wetland, lakes/rivers, desert, tundra, and ice/rock biomes. Technology impacts might then be subjectively evaluated, and expressed in terms of this measure.

Data Considerations

Regardless of which framework and methods are identified, they are useful only if they can be implemented using publicly available and affordable data. To the extent possible, data should be compiled from field-verified results. For retrospective analysis, statistical studies can provide useful information on technical performance.

We suggest that where subjective estimates of key input parameters are required, that they could be periodically reviewed through a systematic process with independent experts.

We further suggest that it could be unnecessary, and sometimes it cannot be justified, to develop quantitative estimates of all of the benefits. Sometimes, the quality and imprecision of input data might not justify detailed numerical results -- order of magnitude estimates might very well be better in these cases. In other cases, the very nature of the benefits in terms of their social or ecological impacts might inherently preclude their being quantitatively estimated. In such situations, these benefits might be just as, or even more, important than other types of benefits that can be quantified. If this were the case, then GPRA reporting and program planning would have to somehow take this into account.

Portfolios of Programs

We suggest that R&D programs could be evaluated in the context of the overall portfolio of options they provide, not simply in terms of their expected individual benefits. We suggest that financial portfolio methods could be used to help construct R&D portfolios among different types of R&D that have different timeframes, different risks, different *types* of risk, and different types of possible benefits.

Some R&D programs would be expected to achieve economic benefits; others would be targeted more to achieving environmental benefits; still others would have security benefits. Likewise, some programs should likely focus on attaining expected prospective benefits; others should focus more on attaining option value, given the great uncertainty in all R&D; and still other programs, especially the science programs, will have as their primary mission the development of new knowledge.

Yet, in all types of programs, "losers" should be expected in these portfolios and decision rules could be developed to help decide which programs to continue and which to terminate.

IDEAS ON A FRAMEWORK AND METHODS FOR ESTIMATING THE BENEFITS OF GOVERNMENT-SPONSORED ENERGY R&D

1. PURPOSE

This white paper provides a common basis and point of departure for discussions at the conference on "Estimating the Benefits of Government-Sponsored Energy R&D." The ideas presented as possible suggestions should not be interpreted as recommendations or preferred approaches for any government agency. Rather, the ideas are offered as a starting point for discussions.

The purpose of this conference is to synthesize insights and information from conference participants, which the energy resource and science offices of the U.S. Department of Energy (DOE) might use to improve their methods for estimating the benefits of their R&D programs.[2]

The motivation for this conference is the priority that these DOE offices are giving to measuring and assessing the performance of their R&D programs. Under the Government Performance and Results Act of 1993 (GPRA), DOE and other federal agencies are required to report annually on their programs' plans and performance. Furthermore, President George W. Bush and the U.S. Congress are placing great emphasis on performance-based assessments and funding of federal programs.

The specific objectives of this conference are to identify major streams of thought on:

(a) a useful methodological framework for identifying the benefits of government-sponsored energy R&D; and

(b) practical approaches for developing improvements to current methods of estimating the benefits of energy resource and science R&D, which might be used to enhance the performance-based management of these programs under GPRA.

The next section of this paper discusses more the motivation for the conference. Section 3 summarizes methods which some of the energy resources and science offices in DOE use to estimate or assess the benefits of their R&D programs. Section 4 presents methods used by some of the other, non-DOE departments in the Federal government. Section 5 summarizes the framework and concepts that were developed in an important study done by the National Research Council (NRC).[3] Section 6 offers suggestions that build on the NRC framework to address issues beyond the scope of that study, but that are important for assessing

[2] Conference facilitators and rapporteurs will identify convergence, as well as divergence, of ideas on methods that might be useful to these DOE offices. The purpose of the conference and of the subsequent draft report, to be written following the conference, is to identify and to suggest methods to these DOE offices, but not to provide recommendations or to act in any advisory capacity.

[3] 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. The report was requested by the Appropriations Committee of the U.S. House of Representatives.

prospectively the benefits of R&D and for enhancing performance-based management of these programs. Section 7 discusses important issues related to implementation of such methods. Section 8 describes the objectives and agenda of each session in the conference.

The NRC framework and the suggestions that build on it are certainly not the only useful set of methods. However, given the context for this conference and the progress made by the NRC committee in its study, we have decided to "pick up where they left off."

2. CONTEXT AND MOTIVATION FOR THE CONFERENCE

An important part of the U.S. Department of Energy's (DOE's) mission is to foster a secure and reliable energy system that is environmentally and economically sustainable. Several offices in DOE play key roles in carrying out this mission. The Office of Energy Efficiency and Renewable Energy (EERE) conducts research to develop and deploy clean and efficient energy technologies. The Office of Fossil Fuel (FE) undertakes research and development to promote the efficient and environmentally sound production and use of fossil fuels. The Office of Nuclear Energy, Science and Technology (NE) advances the application of nuclear technology by investing in new or innovative opportunities for its expanded use. The Office of Science (SC) complements the "energy resources business line" of these other offices by advancing basic research and the foundations of science. All of these offices assess the benefits of their programs to assist their planning and budget development, to meet the requirements of the Government Performance and Results Act (GPRA), and to respond to requests for information from the White House, Congress, and others.

These estimates are important means of assessing both the potential future benefits from public R&D, and the performance and results of past research efforts. Under the Government Performance and Results Act of 1993 (GPRA), federal agencies are required to report annually on their plans and performance. In his "management agenda," President George W. Bush emphasized that the federal government needs to measure the effectiveness of its R&D investments and he chose "energy resources" as the first area to apply new R&D selection criteria, including their contributions to public benefits.[4] The National Energy Policy identifies a number of such potential benefits, including energy security and environmental improvements.[5]

Improved methods of estimating the value of energy R&D can increase the effectiveness of future investments in it. A recent National Research Council (NRC) study, cited in Section 1, developed an initial framework for evaluating the benefits of DOE's past energy efficiency and fossil energy R&D programs. The study's implementation of this framework included conventional methods used in programmatic and economic analysis, as well as cutting-edge methods in need of further assessment and development.

This paper adapts the framework that the NRC study developed to define a starting point for discussions at the conference.

[4] Executive Office of the President, Office of Management and Budget, *The President's Management Agenda, Fiscal Year 2002*, August 2001.

[5] National Energy Policy Development Group, *National Energy Policy*, Washington, DC, May 2001.

3. METHODS USED BY DOE ENERGY RESOURCES AND SCIENCE OFFICES TO ESTIMATE OR ASSESS THE BENEFITS OF THEIR R&D PROGRAMS

3.1 OVERVIEW OF METHODS USED BY THE OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY FOR GPRA[6]

Each year, the Office of Energy Efficiency and Renewable Energy (EERE) estimates future benefits of its portfolio of research and deployment programs. Metrics currently estimated include economic, environmental, and security elements, and are listed in the table below. The types of benefits estimated are not complete – for example, reliability-related security benefits are not currently addressed.

Energy Metrics	Financial Metrics	Environmental Metrics
Total Primary Energy Displaced (Trillion Btu)	Energy Cost Savings (Millions of 1999 $)	Carbon Emissions Displaced (MMTC)
Direct Electricity Displaced (Billion kwh)	Non-Energy Cost Savings (Millions of 1999 $)	Other Greenhouse Emissions Displaced (MMTCe)
Direct Natural Gas Displaced (Billion Cubic Feet)	Consumer Investment (Millions of 1999 $)	CO Displaced (Metric Tons)
Direct Petroleum Displaced (Million Barrels)	EERE Expenditures (Millions of 1999 $)	SO2 Displaced (Metric Tons)
Direct Coal Displaced (Million Short Tons)	Other Government Expenditures (Millions of 1999 $)	NOx Displaced (Metric Tons)
Direct Biomass Displaced (Trillion Btu)	Private Sector Expenditures (Millions of 1999 $)	VOCs Displaced (Metric Tons)
Direct Energy Displaced from Feedstocks (Trillion Btu)		PM10 Displaced (Metric Tons)
Direct Energy Displaced from Wastes (Trillion Btu)		Other Environmental Benefits (Metric Tons)
Other Direct Energy Displaced (Trillion Btu)		

The following chart, reproduced from EERE's FY 2003 Congressional Budget request, is a summary of the results of EERE's *FY 2003 GPRA Benefits Reports*. It is an example of the sort of performance data that GPRA measurements can produce for decision makers to better evaluate the results of funding EERE's program and activities.

[6] This section was written by Mary Beth Zimmerman, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Office of Energy Efficiency and Renewable Energy EERE Programs Projected Benefits by Sector through the Year 2020									
	Total Primary Energy Saved or Produced (quadrillion BTUs)			Energy Cost Savings ($ billions)			Carbon Reductions (million metric tons)		
	2005	2010	2020	2005	2010	2020	2005	2010	2020
Transportation *(equivalent barrels of oil saved, mbpd)*	0.03-0.04 *(0.06-0.14)*	0.5-0.7 *(0.3-0.5)*	2.8-4.7 *(1.5-2.5)*	0.8-3.9	9.4-19.8	31.5-61.5	0.7-2.3	8.9-14.4	54.5-92.1
Industry	0.5	1.3-1.4	3.4-4.3	1.8-1.9	5.4-5.5	16.6-18.0	7.9-8.4	23.0-24.5	54.6-82.7
Buildings	0.3	0.9	1.9-2.8	2.2	7.1-9.3	17.1-29.9	4.7-5.1	16.5-17.0	32.7-51.0
Federal	0.02	0.04	0.06	0.1	0.2	0.3	0.3	0.7	1.1
Power	0.3-0.7	1.0-2.2	2.0-4.9	1.6-2.1	4.2-4.8	10.6-15.2	6.5-28.5	20.4-62.5	36.0-122.6

EERE initiated the effort to develop these metrics prior to GPRA and the methodology has evolved significantly since then. The annual effort is a multi-stage process, initiated with an annual “call” and guidance identifying key budget, energy, economic, and other assumptions to be used in developing program- and sector-level inputs. Each program uses this guidance to develop estimates of likely commercialization dates and initial market penetration rates of the technologies under development. Program assumptions are reviewed on a rotating basis by AD Little to help ensure consistency and improve projections. Interactions among technologies developed (e.g., when two technologies under development compete for the same market segment) are addressed by integrating technology results across sectors and the economy as a whole.

The reference case for EIA’s most recent Annual Energy Outlook (AEO) is used as the baseline for analysis, although it is modified to “back out” any program results already included in the AEO. This approach provides forecasted baseline energy prices and market sizes, as well as incorporating underlying (non-program) improvements in energy technology performance. To help ensure that analysis occurs on a marginal, rather than average basis, EIA's National Energy Modeling System (NEMS) is run at lower energy demand levels to determine which fuel sources might be most effected as efficiency and renewable technologies make their way into the market.

3.2 MEASURING FUTURE BENEFITS FOR FOSSIL ENERGY RESEARCH AND DEVELOPMENT[7]

Most past Fossil Energy (FE) R&D benefits estimation has focused on two broad program categories:

1. Fossil Fuel Conversion – conversion of coal and gas to electricity and other fuels, and
2. Fossil Energy Resources – domestic oil and gas supply.

The nature of these programs and their benefits are very different, which has led to rather different approaches for calculating their future benefits.

3.2.1 Fossil Fuel Conversion

FE has been estimating future benefits for many years. The benefits resulting from deployment of advanced fossil generation and environmental technologies (including CO_2 sequestration) are quantified in terms of dollars saved due to deployment of less expensive technologies:

- Increased GDP due to the use of lower cost technology;
- New direct and indirect domestic jobs;
- Reduced emissions of SO_x, NO_x, and carbon dioxide; and
- Dollars of exports.

These benefits estimates are based on the the Energy Information Agency (EIA) forecast of electricity demand growth through 2020, and extrapolation of this forecast beyond 2020 to estimate the demand for new gas-fired and coal-fired electric generators in the U.S. through 2050. In addition, several studies (by WEFA, Resource Dynamics Corp, Parsons, and others) are also used which estimate the export of clean coal technologies, the use of advanced emissions control technologies, and the associated macroeconomic effects. In this analysis, no effort is made to parse the credit for the benefits between industry and government.

With respect to estimating the benefits of deploying advanced fossil generating technologies in the U.S., the methodology assumes that all new fossil plants built after 2015 are high-efficiency Vision 21 plants with sequestration of carbon emissions. The existing inventory of fossil plants is assumed to retire on a business-as-usual schedule. Generation from new Vision 21 plants is assumed to be 10% less expensive than an equivalent amount of generation from new conventional fossil plants. Carbon emissions reductions are estimated by comparing total emissions from the electric generation sector through 2050 with base case carbon emissions assuming new conventional gas and coal plants deployed without sequestration.

3.2.2 Fossil Energy Resources

Estimates of benefits of advanced technology for oil and gas production depend heavily on the nature of the existing resource. Extensive efforts have been undertaken to measure benefits using economic and engineering models. FE developed the first oil model in 1984 in conjunction with the National Petroleum Council. Model development included input from experts from industry, universities, government, and private nonprofit organizations. Over time,

[7] This section was written by Jay Braitsch, Office of Fossil Energy, U.S. Department of Energy.

this model has evolved into an integrated suite of databases and analytical computer models, all striving to emulate the actual complexities of producing domestic oil. This engineering and economic model was joined by another model to mimic domestic gas production. The models contain actual data from the Nation's oil and gas wells and fields.

Within appropriate bounds set by other databases, like those from EIA, the two engineering based models analyze the amount of oil and gas on a field by field basis to calculate how much was, is, or will be produced over a specified time interval. This is the oil and gas world without FE R&D.

FE R&D includes a portfolio of oil and natural gas projects. For each project FE develops key parameters such as the probability of success, likelihood of the technology penetrating into the marketplace, and the size of the applicable oil or gas resource; and analyzes the potential impacts. Results for individual projects are then fed into the oil and gas models to estimate impacts with FE R&D. The difference between these two simulations provides estimates of the benefit of FE R&D.

The models use a consistent methodology, and the results are periodically peer reviewed and projects validated. The primary benefit measured is the additional oil and gas resulting from FE R&D. This approach has also allowed FE to estimate economic benefits and new direct and indirect jobs, as well as certain environmental benefits, like emission and effluent impacts.

Currently, staff at the National Energy Technology Laboratory are working to integrate separate models into a single one to permit more accurate and efficient benefit computations.

3.2.3 Future Directions

Today's standard decision-making tool is Net Present Value (NPV). NPV calculates the value of a project by predicting future payout, adjusting for the risk, and subtracting the investment cost. NPV does not account for the ability of government and industry leaders to react to new circumstances. FE has begun to explore the use of Real Options to better quantify the value of its programs. Real Options is an investment valuation tool that accounts for and credits flexibility. Given a highly unpredictable future, the Real Options approach assesses the value of spending money now so that in the future there is better information on which to exercise the option to deploy, discard, or continue to develop a technology.

3.3 OVERVIEW OF METHODS USED BY THE OFFICE OF SCIENCE[8]

The challenge of evaluating science programs has been the subject of widespread attention for many years, including initial recognition within the Government Performance and Results Act, and more recently by significant focus of the National Academy of Science's Committee on Science, Engineering, and Public Policy (COSEPUP), as well as the White House Office of Management and Budget's present efforts to develop separate evaluation criteria for basic research. Problems arise because of the inherent difficulties in modeling the non-linear innovation and knowledge diffusion process --- knowledge that is the primary goal of the research and the principal output of science. Consequently, the Office of Science draws from a

[8] This section was authored by Robert Vallario of the Office of Science, U.S. Department of Energy.

broad array of methods, and is researching and developing many more, to evaluate its basic research programs.

Across the various groups exploring this issue, some elements appear to emerge as common themes.

- Evaluation is more successful around the process and outputs of science (sometimes referred to as process-outcomes)
- Expert review forms the cornerstone for evaluating the process and outputs of science, and the more useful dimensions of analysis include:
    - Quality of the science
    - Relevance of science
    - Leadership and/or Performance of the science
- Evaluating the outcomes (and estimating the benefits) of science, while a desirable goal, cannot completely and effectively account for the complexities of knowledge diffusion and the broad range of interactions and factors that contribute to innovation.
- Techniques that explore the downstream impacts are often incomplete, and provide only focused insights into the benefits through various indicators.

Listed below in Table 1 are evaluation techniques that are currently employed within the Office of Science (SC) to evaluate, either retrospectively, prospectively, or both, the science programs. Collectively, these techniques address the basic research and the infrastructure stewardship role of SC, the latter consisting of the vast array of scientific user facilities and premier tools of science, the human capital, and the critical support and sponsorship for core science capabilities that SC contributes to the nation's public science enterprise.

Table 1. Current Evaluation Methods Within the Office of Science

•Regular peer review for the university grant programs, laboratory research programs, and facilities.
•Cost, schedule, technical scope, and management reviews ("Lehman Reviews") of construction projects, i.e., major scientific facilities
•Occasional Advisory Committee reviews of facilities and programs
•Occasional external assessments of programs, e.g., by JASONS or NRC
•Metrics and customer survey for facilities
•Historical retrospectives and annual highlights
•Tracking of a very (very!) few selected metrics such as prizes/publications/PI leadership
•Discipline/sub discipline international benchmarking

Beyond these more traditional tools, the Office of Science has been sponsoring research and investing staff resources in a variety of promising areas intended to help illuminate the pathways of knowledge diffusion and, ultimately, improve the evaluation of science outcomes. Although no individual technique appears a panacea for the aforementioned difficulties, collectively they seem to offer promise, providing a powerful, complementary perspective to the continued mainstay of expert review.

Table 2. Evaluation Methods Under Consideration and/or Development by the Office of Science

•Mission Mapping
•Outcome Mapping
•Patent, Bibliometric, Data Mining & Visualization Tools
•Foresighting
•Case Study Enhancements (Resource Guide)
•Options Theory
•Network Analysis
•Expanded International Benchmarking
•Innovative S&T Metrics

Additionally, the categorical/topical structure of one item, Case Study Enhancements, further reveals methodological areas that SC is exploring, both through continued research, and through pilot studies based on SC's recently completed "Science Manager's Resource Guide to Case Studies". Methodologies include:

•Classic, Interview- and Records-Based Method
•Expert Review Method
•Historical Tracing Method
•Bibliometrics and Citation Methods
•Content Analysis Methods (Co-Word, Data Tomography, etc.)
•Sociometric/Social Network Methods
•User/Participant Survey Method
•Benefit-Cost (Cost-Benefit) Methods
•Statistical/Econometric Methods
•Key Indicator Method

4. METHODS USED BY OTHER FEDERAL AGENCIES TO MEASURE THE OUTCOME-RELATED PERFORMANCE OF THEIR PROGRAMS

4.1 MEASURING THE BENEFITS OF THE ADVANCED TECHNOLOGY PROGRAM[9]

4.1.1 ATP's Mission and Operations

The ATP partners with industry to accelerate the development of innovative technologies for broad national economic benefit. The program's focus is on co-funding collaborative, multi-disciplinary technologies and enabling technology platforms that appear likely to be commercialized, with private sector funding, once the high technical risks are reduced. Industry-led projects are selected for funding in rigorous competitions on the basis of technical and economic merit. Since 1990, ATP has co-funded 581 projects, with 1,250 participants and another 1,200 subcontractors. More than 60 percent of the projects are led by small businesses. More 160 different universities and more than 20 national laboratories participate. ATP has committed over $1.8 billion of funding to these projects, and industry has committed another $1.75 billion. Although ATP competitions are open to all technologies, to date 35 projects, with $30 million in ATP funding, are directed at solutions to the nation's energy challenges.

4.1.2 ATP's Multi-Component Assessment Program

Evaluation has been a central part of ATP operations from the beginning, as a management tool to provide feedback to project selection and program operations and to meet requests from external sources for ATP program results.

The ATP has developed a multi-component evaluation strategy to provide measures of progress and performance matched to the stage of project evolution:

- for the short-term, from the time of project selection and over the course of the ATP-funding period;

- for the mid-term, as commercial applications are pursued, early products reach the market, and dissemination of knowledge created in the R&D projects occurs; and
- for the longer-term, as more fully-developed technologies diffuse across multiple products and industries, with related net impacts on formation of new industries, job creation, and U.S. economic growth.

Current approaches to evaluation include:

- statistical profiling of applicants, projects, participants, and technologies
- progress tracking of all projects and participants (through a business reporting system and other surveys)
- status reports of all completed projects, with a performance rating against ATP's mission

[9] This section was written by Jeanne Powell, Senior Economist, Economic Assessment Office, Advanced Technology Program.

- detailed microeconomic case studies of selected projects, including the following metrics: public rate of return (return attributable to ATP), private and social rates of return, net present value, and benefit-cost ratio
- econometric and other statistical studies of innovation, productivity, and portfolio impacts, including use of control groups
- macroeconomic analysis extending firm and industry level impacts to impacts on GDP and national employment
- development and testing of new assessment models and techniques.

The ATP's Business Reporting System, a unique internal database created in 1993, tracks progress during and after the performance of each project. This system first identifies the project's goals and expected commercial advantage, its strategies for commercialization, and collaborative activities and experiences of its members, with emphasis on comparing what ATP funding makes possible with what would likely occur in the absence of ATP funding. Each project is evaluated in terms of the effect of ATP on the project's timing, scale, scope, risk level, ability to do long-term R&D, and the ability to attract private investment dollars. After the project is finished, the ATP's Economic Assessment Office follows up with regular surveys and studies of progress in commercialization and knowledge dissemination. For select projects and programs, detailed benefit-cost analyses are performed.

4.1.3 ATP's Evaluation Results

Recently completed mini case studies of ATP's first 50 completed projects provide an evaluation of the performance of each project using ATP's Composite Performance Rating System. Each project is scored on a set of measures of knowledge creation and dissemination and progress toward commercial goals.

ATP's Composite Performance Rating System[10]

Knowledge Creation and Dissemination Measures	**Commercialization Progress Measures**
Technical awards Collaborations Patent filings Publications and presentations New product/process in market or expected soon	New product/process in market or expected soon Attraction of capital Employment gains Business awards Outlook

The results from all the measures are used to construct a composite performance score to indicate the overall project effectiveness against ATP's mission (measured 2-3 years after the end of ATP funding). The result is a four-star system of ratings, with scores ranging from zero to four stars. The results of this analysis for the first 50 completed ATP projects find that sixteen percent of the projects are top-rated in terms of overall project performance, with four stars. Twenty-four percent are in the bottom group of zero or one stars. Sixty percent make up the middle group.

Not all ATP projects are fully successful. The program's emphasis on funding high-risk, technology development that the private sector is unwilling and unable to fund alone dictates that most projects will fail to accomplish all their goals. Some projects are stopped before

[10] The scoring system was developed by Rosalie Ruegg, TIA Consulting.

completion of the funding period. Others fail to meet all their technical goals, or encounter business difficulties before the technologies are commercialized.

Evaluation studies to date suggest ATP is delivering results: 1) Estimated net benefits (including projections) from just a few projects exceed the total cost of ATP to date; 2) a vast proportion of these benefits extends beyond the organizations who received ATP funding, in keeping with the program's emphasis on generating significant spillover effects; and 3) there is substantial evidence that ATP has made a difference in the ability of the nation to realize these benefits.

The ATP evaluation studies are available on the website at: www.atp.nist.gov/eao/eao_pubs.htm.

4.2 FEDERAL RAILROAD ADMINISTRATION'S (FRA'S) R&D PROJECT EVALUATION AND INVESTMENT ANALYSIS[11]

At the urging of the Transportation Research Board (TRB) Committee for Review of the FRA R&D Program, FRA has developed a structured process to identify safety research areas and select specific safety R&D projects for funding. The approach consists of five logical steps that were applied to the FRA's safety R&D program. Subsequently, as new information becomes available about sources of hazards, the logical steps may be followed for specific types of safety hazards to add to the list of potential safety R&D projects.

Step 1: Review of Rail Industry Historical and Potential Harm

The first step in the FRA safety R&D project development and selection process is a review of recent rail industry harm data and an assessment of causes of potential safety hazards. In this context, harm is considered to be the aggregate cost of fatalities, injuries and property damage due to rail accidents. Historical hazard data is compiled in FRA rail accident databases and accident investigation reports. Potential for future safety hazards can be understood by reviewing rail industry operating trends with expert knowledge of how railroad accidents occur.

The four relevant databases which hold historical rail incident data are the FRA's Rail Accident/Incident Reporting System (RAIRS), Highway-Rail Grade Crossing Accident/Incident Database, Railroad Injury and Illness Summary Database, and the Research and Special Projects Administration's (RSPA's) Hazardous Materials Incident Database. The information in these databases is very detailed in terms of accident causes. However, these databases, typically, do not address specific contributing causes that result in railroad accidents or incidents.

Detailed accident reports from the National Transportation Safety Board (NTSB) and the FRA are the most important source of information, compiled by experts, about accident circumstances that contribute to hazards. Since accident databases and accident reports can only reflect historical accident causes and circumstances, railroad industry operational trends

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[11] Chapter 4, Five Year Strategic Plan for Railroad Research, Development, and Demonstrations, FRA, soon to be released. Provided by Robert C. Ricci of the Volpe Center.

must also be taken into account. In this way, an understanding of causes of hazards that are not reflected in the historical databases can be developed.

Step 2: Conduct Failure Analysis

For a given cause of an accident, or factor contributing to hazard, fault-tree logic is applied to identify specific items to be addressed by countermeasures. These specific items represent points along the accident chain-of-events at which the accident, or subsequent harm, or both, could have been prevented. Thus, the fault tree approach permits identification of multiple causes of accidents, enriching the information gleaned from the accident databases, which typically assign a single, primary accident cause. Countermeasures are proposed with the goal of breaking the accident or hazard chain-of-events at the identified points.

These countermeasures are advanced with an understanding of current regulatory and industry practices for the relevant area of rail operations.

Types of possible countermeasures include:

$ New or revised regulations
$ Industry standards and best practices
$ Equipment and infrastructure improvements
$ Enforcement
$ Education.

Step 3: Survey Government and Industry Countermeasures and R&D Requirements

Once specific countermeasures are identified, FRA R&D will review current and potential industry and government countermeasures to identify and assess areas of technological opportunity for R&D. That is, FRA R&D will identify countermeasures that would be enabled by R&D. For example, a potential operating rule may need research into the train speed regimes at which a particular type of train control system affords safe operation.

Step 4: Develop and Rate Individual Projects

For each countermeasure that may be aided by R&D, one or more R&D project summaries are developed to describe projects that provide information to enable the countermeasures. The project summaries are structured descriptions of projects that will be used to compare and select projects during R&D program development. Project summaries address expected outputs and outcomes, project costs and durations, as well as implementation issues for project results. Based on the project summaries, projects are then rated according to objective criteria for expected contribution to safety and likelihood of success. For a given program area, these project ratings are plotted in two dimensions (likelihood of success versus contribution to safety) to provide a high-level comparison tool for the project selection process.

Step 5: Select Projects and Assign to Program Areas

The last step in the FRA safety R&D program development process entails selecting projects for each program area based on the two-dimensional plots and project summaries. The goal is to select the best research opportunities available to obtain the best return on investment possible from the FRA R&D budget. That is, the most highly rated projects, regardless of program area, are selected to develop budget request estimates. Once the budget has been finalized, the projects are revisited, and funding levels and schedules are adjusted appropriately. The FRA R&D budget request, for each program area, becomes the sum of the funding required for each of the selected projects in the program area.

This process, augmented by Congressional directives as well as by requirements to carry out research in direct support of rulemakings mandated by law, was used by FRA in the preparation of its FY 2002 and FY2003 budget requests and its soon to be released *Five-Year RD&D Plan*. The FRA anticipates that it will continue to use it in the future in the development of its R&D program.

5. NATIONAL RESEARCH COUNCIL'S METHODOLOGY FOR DEFINING THE BENEFITS OF ENERGY R&D[12]

There are many ways of addressing the stated objectives of the conference. However, the recent study done by the National Research Council (NRC) Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy provides an important context for the conference. In legislation approving the FY 2000 energy R&D budget for DOE's energy efficiency and fossil energy programs, Congress directed the NRC to conduct an evaluation of the benefits that have accrued to the nation since 1978 from these programs. This charge was *a retrospective* look at the benefits that had been realized to date. The NRC did not consider any prospective benefits from the programs.

To undertake its task, the NRC developed and implemented a methodological framework to estimate the retrospective benefits of individual energy efficiency and fossil energy R&D programs. Thus, the framework we suggest as a starting point for discussions at the conference is adapted from the one developed in the NRC study. In this section of the paper, we review this NRC methodology. In Section 6, we turn to a discussion of "strawperson" ideas for building on and extending NRC framework because of the need to consider R&D programs prospectively, for the purposes of GPRA and program planning.

5.1 METHODOLOGICAL FRAMEWORK

To undertake this task, the NRC first had to develop a methodology or framework to assess what were the benefits realized. The NRC recognized that there are many different types of benefits. The NRC believed that the benefits considered foremost must meet DOE's stated

[12] James L. Wolf authored Section 5 and Sections 7.4 and 7.5.

mission - which the NRC culled by reviewing statures and public mission statements issued by DOE. The NRC viewed the public benefits as:[13]

- Economic: Measured by the change in the market value of goods and services that are produced under "normal" economic conditions resulting from the introduction of a technology stemming from DOE research. The benefit is measured net of all public and private costs, and can typically be reflected in market prices of goods or services in the economy. The NRC considered the costs for the program - the costs borne by DOE and private industry in conducting the R&D -, as well as the costs of the technology borne by the end-user or consumer so that the net benefits were assessed. In essence, an economic benefit is reducing the cost of energy services.

- Environmental: Based on changes in the quality of the environment because of DOE research. The benefit is typically not measured directly by changes in market prices, but rather by some measure of the value society is willing to place on changes in the quality of the environment.

- Security: Measured by changes in the probability or severity of abnormal energy- related events that would adversely impact the overall economy, public health and safety, or the environment. Traditionally, this was an oil focused concern, but recently has expanded to include the reliability and security of the energy supply infrastructure- both electric and gas.

The NRC recognized that R&D might lead to benefits even when a technology developed by that R&D does not enter the market immediately or to a significant degree. This lack of commercial deployment might due to changes in the forecasted economic or policy conditions, or to technological barriers. To account for this uncertainly, and to reflect the different degrees of technology development in the snapshot in time the NRC was evaluating the benefits, the NRC established three categories:

- Realized Benefits: These benefits have been realized or are almost certain to be realized in the near future - the technology is developed and economic and policy conditions are favorable for commercialization. The NRC included all lifecycle benefits of the units of the evaluated technologies that were projected to be installed by the year 2005.

- Option Benefits: This category covered technologies that are fully developed but for which existing economic or policy conditions are not likely to be favorable for commercialization. To be considered an option by the NRC, the technologies needed to be favorable for commercialization under some credible or plausible circumstances.

- Knowledge Benefits: R&D, whether successful or not, typically produces knowledge benefits. This scientific knowledge produced by R&D is a key component of DOE's mission. The NRC considered as knowledge benefits scientific knowledge and useful technological concepts that have not yet been incorporated into commercialized results from the R&D program but hold promise for future use or are useful in unintended applications. These hold value over and above that accounted for in the other areas of realized and option benefits.

[13] Note that these benefits are those from energy technologies. Other R&D programs and technologies might have other types of impacts, e.g., public safety, mobility, and reduced (as well as economic, environmental, and security) congestion in the transportation sector.

The following table reflects the interplay of the stages of technology development and economic and policy conditions as the NRC conducted its retrospective review of benefits.

Technology Development Economic/ Policy Conditions	*Technology Developed*	*Technology Development in Progress*	*Technology Development Failed*
Will be favorable for commercialization	Realized benefits	Knowledge benefits	Knowledge benefits
Might become favorable for commercialization	Options benefits	Knowledge benefits	Knowledge Benefits
Will not become favorable for commercialization	Knowledge benefits	Knowledge benefits	Knowledge benefits

5.2 DERIVATION OF COLUMNS FOR THE BENEFITS MATRIX

This assessment of the types of benefits led the NRC to construct the following matrix to evaluate the R&D programs conducted by DOE. It reflects the interplay between stages of technology development, economic and policy conditions, and economic, environmental and security benefits.

Matrix for Assessing Benefits and Costs

	Realized Benefits and Costs	Options Benefits and Costs	Knowledge Benefits and Costs
Economic Benefits and Costs			
Environmental Benefits and Costs			
Security Benefits and Costs			

Since the NRC study was only retrospective and charged with evaluating benefits achieved to date, only "realized" benefits and costs were evaluated -- there was no column for "prospective" benefits or costs. If DOE uses this framework for program planning and budgeting looking toward the future, a column of prospective benefits and costs should be added to the matrix.

To do its evaluation, the NRC conducted case studies of 22 fossil energy and 17 energy efficiency programs. The case studies were evaluated both quantitatively and qualitatively to fill out the matrix for each program. The full NRC report is "Energy Research At DOE – Was it

Worth it? Energy Efficiency and Fossil Energy Research 1978 to 2000." One of the NRC's recommendations was that DOE should convene a workshop to refine and address issues the NRC identified in using the framework so DOE could begin the implementation process.

5.3 MAJOR ISSUES CONSIDERED – ALL NOT NECESSARILY RESOLVED

5.3.1 Establishing a Baseline for Realized or Projected Benefits

Looking both retrospectively as well as prospectively in assessing an R&D program, the technology under evaluation must always be compared with the "next best alternative." Technologies change and improve over time, and it was difficult for the NRC to retrospectively assess over different time periods what the next best alternative was.

Looking prospectively, this is an even more difficult challenge. One needs to project what the next best alternative technology to the R&D program under consideration is projected to be over a long period of time - perhaps decades. This requires judgment and rigor, but the NRC did not tackle this issue since it was only charged with a retrospective evaluation.

Indeed, in its charge to evaluate realized benefits to date, the NRC was extremely limited in considering the projected future installations of any technology. The NRC imposed this restriction due to uncertainties about both technology development and future economic and policy conditions.

The NRC adopted a "2005 year rule" – it allowed the lifecycle benefits of all the technologies that were projected to be installed by 2005 to be considered in its evaluation of "realized benefits", but none after that date. The benefits for a technology installed in for example 2003, with a 20 year life, would get its life-cycle benefit assessment in the realized benefit column. Any technology installed in 2006 or after got none.

Looking prospectively, a baseline must be established to estimate prospective benefits. This baseline is a projection based on the "next best technological alternative." Then a projection based on the development of the new technology must be developed at a modeled projection rate. Finally, the effect of the government program must be considered and the differences in benefit curves somehow allocated if it is not found that "but for" DOE this technology never would be developed.

This conference needs to extend the NRCs work and develop methodologies that DOE can use to address these issues, recognizing both data constraints and cost considerations in DOE's planning activities. The primary reason for extending the NRC framework is that the scope of its study was limited to being a retrospective analysis, whereas, for the purposes of GPRA and program planning, prospective estimates are needed on the benefits of R&D programs.

5.3.2 Effect of Government Program

To evaluate the benefits of the government R&D program, one must evaluate what the effect of the program was or is projected to be. The total impact or benefit of a technology is not necessarily the effect of the government program of R&D for that technology.

For example, if the government provided 10% of the funding to develop a technology that has an estimated $100 million of economic benefits to date - should the government expenditure get credit for all $100 million of benefits? In the vast majority of cases, it is highly unlikely that "but for" the DOE R&D program, the technology never would have been developed. The benefits attributable to a technology and the benefits attributable to the government program that helped develop that technology need to be separately considered.

The NRC developed a rule of thumb for considering the effect of the government R&D program. It assumed the DOE R&D program advanced the introduction of new technology into the market by 5 years. It adopted this rule in all the case studies examined for consistency. In each case, it did find a significant DOE role. In essence, the NRC compared two traditional "S" shaped" market penetration curves - one starting 5 years earlier than the other due to the effect of the DOE program. The curves were the actual penetration observed in the market and a similar shaped one starting 5 years later. The benefits of the program were the difference in the sum of benefits under the benefit curves due to the technology.

Questions abounded about whether this was a reasonable assumption, if it should vary by case study, or if there were other ways to assess the impact of the government program. What factors, such as the percentage of government funding, stage of technology development or nature of the industry, are appropriate to consider if the effects should vary on a case by case basis? How are these vetted for reasonableness? The issue on assessing the effect of the government program needs more consideration and relates to the question of baseline discussed previously in Section 5.3.1.

5.3.3 Nature of Benefits

In evaluating benefits, the NRC found that most of the focus of DOE has been on economic benefits. Several points need to be made, however, about all categories of benefits and the issues that arose in the NRC's examination.

In evaluating economic benefits, The NRC did not believe it appropriate to consider any macroeconomic stimulation to the economy or the creation of jobs as an economic benefit from any R&D initiative. Similarly, any potential trade benefits were not deemed appropriate to include.

On environmental benefits, the NRC considered the saving in costs from achieving any given standard of emission control as an economic benefit. Environmental benefits result only if there is a net improvement in the quality of the environment.

The NRC did calculate the tonnage of pollutants that the technology avoided. The NRC looked at the wide range of values that have been done assessing environmental damage for various pollutants, but declined to adopt any one of them to attribute an economic value to the pollution prevented.

Security benefits – both oil and energy infrastructure reliability and safety- were difficult for the NRC to address. The security benefits were considered as reductions in the probability or severity of an energy disruption. Both quantitatively, and even qualitatively, these were hard to evaluate for the R&D programs examined.

The barrels of oil saved or produced by DOE sponsored technologies could be calculated in most instances, but the linkage to security and how to evaluate its significance was difficult. This linkage to security and assessment in the area of energy infrastructure was even more difficult. How significant was the benefit achieved by the program? What were the criteria for how should it be measured? These issues need more resolution.

Option benefits were precisely defined as technologies for which development work was done and successful, but for which economic or policy conditions were not present to enable it to currently enter the market to a significant degree. To be considered as an option benefit, the technology has to be able to enter the market under situations that have “credible” possibilities of occurring. It may be viewed as a form of prudently purchased insurance.

The NRC found that several of the DOE programs had developed options, but this was a retrospective judgment. When undertaken, these programs were trying to develop technologies that were projected to enter the market. The NRC did not attempt to value these option benefits either quantitatively or qualitatively.

Especially if it is deemed appropriate for DOE to develop options as a goal in its program development and part of its portfolio, then a better a priori assessment of option values is needed. A process for defining plausible or credible circumstances needed to make the option viable also needs to be developed.

The NRC considered knowledge benefits as scientific knowledge and useful technological concepts resulting from R&D that have not yet been incorporated into commercial results of the program but hold promise for future use or unintended applications. This category was very broad and is almost an “everything else” category of benefit. More precision is needed with criteria to evaluate how significant the knowledge gained is and how it should be categorized.

6. BUILDING ON THE NATIONAL RESEARCH COUNCIL'S STUDY -- IDEAS ON FRAMEWORK AND METHODS FOR ESTIMATING THE BENEFITS OF GOVERNMENT R&D

The National Research Council (NRC) report offers a point of departure for efforts to improve methods for estimating the benefits of government-sponsored energy R&D. With this conference, we build on that study, addressing several of the areas that the NRC committee identified, which were discussed in Section 5.3:

(a) prospective analysis of benefits,
(b) option valuation,
(c) knowledge valuation, and
(d) security, economic, and environmental benefits.

Each of these four areas is the subject of one of the workshops in the conference. Workshop A focuses on the prospective-benefits column in the benefits matrix discussed in Section 6.1. Workshop B focuses on the option column. Workshop C focuses on the knowledge column. And Workshop D addresses the rows of the matrix. The format of the conference, which is described more fully in Section 8, is geared to having participants offer their suggestions for building on the NRC study in these four areas. All four workshops also have a session on the additional topic of how measures of benefits might be used in GPRA-related program planning, evaluation, and decision-making.

To give examples of how conference participants might consider building on the NRC study, we offer some ideas in each of the four areas.

6.1 PROSPECTIVE ANALYSIS OF BENEFITS

6.1.1 Definition of Expected Prospective Benefits

By *prospective* analysis, we mean one that looks into the future. In contrast, the scope defined for the NRC study was limited to a *retrospective* analysis of the benefits of past R&D programs. As described in the previous section, the degree of certainty and time frame of these benefits were classified as being "realized," including the foreseeable future to the year 2005, "option" benefits, and "knowledge" benefits. Prospective benefits were not of primary concern, given the stated scope of the NRC's study. However, they are of the utmost concern in program planning and decision making.

Before proceeding to consider the question of prospective benefits, we suggest that the NRC committee's definition of "realized benefits" could be modified. The NRC definition includes benefits that have already occurred (i.e., this "scenario" has a probability of occurring of 1.0), *plus* those from a "best guess" forecast of the likely market penetration and sales of the technology in question, up to the year 2005. Option and knowledge benefits are considered to be *in addition* to these realized benefits.

The definition of realized benefits that we suggest differs from the NRC definition. In the NRC study, the benefits between now and the year 2005 (or, more generally, five years from now, for example) would be part of the realized benefits. Whereas, we suggest that these benefits could be part of the prospective benefits, which would extend from the current year to at least the year 2020, or whatever time horizon is required. The definition we suggest above for realized benefits would include only the benefits from deployments of the technology, developed at least in part by the R&D program, up to the current time.

Consistent with the NRC study, we suggest that the benefits of the technology in question be net of its R&D costs, *as well as* the benefits of the next-best alternative. That is, a next-best alternative -- perhaps a hypothetical one -- would be identified and its economic, environmental and security benefits would be subtracted from those of the technology in question.

In a prospective context, *all* benefits are prospective, including option and knowledge benefits. But for the purpose of this discussion, we generally use the term "expected prospective benefits" to refer to those under the most likely scenario. To account for these prospective benefits, we suggest adding a column to the NRC benefits matrix. This idea is illustrated in the following figure.

Modification of National Research Council Committee's Framework
For Identifying the Benefits of Energy R&D

	Realized Retrospective	Expected Prospective	Option	Knowledge
Economic				
Environmental				
Security				

We suggest that the expected prospective benefits could be defined as those expected from future deployment of a technology developed as a result of R&D, under the projected baseline set of market and policy conditions, compared to the expected conditions under the same projected baseline, without the technology. Thus, estimation of expected prospective benefits requires a baseline characterization of future energy markets without the government research, and an estimation of how baseline markets will react to the new or accelerated technology, including its expected market penetration.

We suggest that conference participants consider several alternative ways of defining and estimating the expected prospective benefits:

(a) Benefits in the reference case (sometimes referred to as the "most likely scenario") of an energy-market forecasting model, that would be augmented by the technology under consideration,

(b) Mathematical mean or expected value of the benefits, as calculated using an energy-market forecasting model, again with each scenario being augmented by the technology under consideration,

(c) Benefits based on extrapolation of technology deployment, in cases where there is already limited deployment,

(d) Benefits based on subjective assessments of the likely market penetration of the technology,

(e) Subsumed in the option value, which includes all prospective benefits (except knowledge benefits).

(a) <u>Expected Prospective Benefits are Those in the Projected Baseline, but *With* the DOE R&D Program Under Consideration, Versus Those in the Projected Baseline *Without* the Program</u>

In this first possible definition, the expected prospective benefits are the economic, environmental, and security benefits that result from the future deployment of the technology in question, under the projected baseline set of conditions, versus the situation under the same projected baseline, without the technology.

This definition is analogous to that used by the NRC committee for retrospective benefits in that the benefits of the technology in question are net of those of the next-best alternative. In the prospective case, the next-best alternative is reflected in the projected baseline, which includes technical improvement, without the technology in question. The question of defining the projected baseline is addressed in Section 6.1.2.

The benefits of a technology depend considerably on its technical performance, particularly those aspects that affect its economic, environmental, and security impacts. The actual performance of a new technology will generally differ, at least to some extent, from its design or target level. We suggest here that the projected performance of the technology could set as the most likely actual performance, rather than the design or target level.

The projected market penetration of a new technology is another key input parameter that greatly affects the magnitude of its expected prospective benefits. In this regard, we suggest that it could be preferable to characterize the attributes of the technology and to use a model to project how well it will do in the market, than to simply assume a certain level of market penetration after some number of years.

The model used for this purpose would be the same one used for the projected baseline. Then, the Reference Case run of that model would be the projected baseline, *without* the technology in question. A run of the same model, augmented with a simple representation of the technical performance and supply (curve) of the technology in question, would be the case *with* the R&D program. The difference between the economic, environmental and security conditions in these two runs would be the expected prospective benefits of the technology.

We suggest that the results of these calculations, which are projections of the annual net benefits of the technology, could be reported in the following ways (i.e., both ways):

- Total net benefits in five-year intervals, in "real" dollars, but without discounting, *and*

- Net present value, in which the estimated future benefits and costs over the operating life of equipment deployed are discounted.

The first way of reporting the results is more intuitively informative for most people.[14] The second way of reporting the results provides a single value for the present value of the stream of net benefits.

We also suggest that DOE offices could consider attaching a probability to these expected prospective benefits occurring. This probability would be the probability of the projected baseline occurring (which could be set DOE-wide) multiplied by the probability of technical success under the projected baseline conditions (which would be estimated on a program-by-program basis following a uniform set of guidance). These two probabilities reflect market risk and technology-specific risk, respectively. It is obviously difficult to speculate on these probabilities because there is such great "uncertainty about these uncertainties." However, if done, these estimates could be used to improve R&D portfolio management. Portfolio management involves risk management.

[14] We suggest that tabulations that report the benefits in five-year intervals have a footnote stating that the present value of benefits in distant years is considerably less than those in the near-term, other things being equal.

The option benefits, incidentally, would be those associated with scenarios other than the reference case. Methods for estimating the option benefits would still need to be determined (refer to Section 6.2).

(b) Expected Prospective Benefits are the Mean Value

With this alternative definition, the expected prospective benefits are those that correspond to the mean value in a mathematical sense. A range of scenarios is considered for the market penetration and use of the technology. This range might be represented by a probability distribution(s) of values for key parameters that affect the forecast.[15] Alternatively, the range might be represented by a limited number of alternative scenarios.

With probability distributions, a Monte Carlo analysis is a common approach for calculating expected outcomes. With a limited number of scenarios, each can be assigned a probability value, with the values adding to one. In either case, the expected present value of the net benefits can be calculated.

The option benefits would in this case be either *zero* (because *all* possible scenarios including the very unlikely ones are taken into account in calculating the mean value), or treated as in the NRC study (if the sum of the scenario probabilities is less than one).

(c) Benefits Based on Extrapolation of Technology Deployment

In cases where there is already limited deployment, an approach that could be used is to use data on the market penetration of the technology thus far. These data could be used to estimate, or example, the parameters of a logistic curve commonly used to predict the diffusion of new technologies.

The calibrated equation for market penetration could then be used to predict the future market penetration of the technology. The approach is relatively straightforward but has a major disadvantage that it cannot be used unless sufficient data exist to estimate a statistical model (at least thirty years of annual data -- in which case the technology is hardly a new technology in need of government R&D).

(d) Benefits Based on Subjective Assessment of Likely Market Penetration

Another approach is to obtain predictions of the likely market penetration of the technology over time. For example, predictions could be obtained on the ultimate market penetration of the technology and the time expected to reach that level. Then, interpolation can be done, assuming a specific type of equation, such as a logistic curve.

This approach is relatively simple to implement, but has the disadvantage that it is difficult to obtain unbiased subjective predictions of market penetration levels. For example, R&D program managers likely know the potential of the technologies they are developing as well as anyone, but they are also likely to be advocates of these technologies. The predictions are also unlikely to be consistent with the macroeconomic, policy and regulatory assumptions used in DOE's other models that are used to help develop its forecasts and policy positions.

[15] In developing estimates of such distributions, the burden on respondents should be kept to a minimum. For example, the functional form of the probability distribution can be assumed *a priori* and the specific distribution obtained through one or two simple, intuitive questions.

(e) Expected Prospective Benefits Are Subsumed in the Option Value

In this case, the definition of an option, which we suggest, differs from the NRC definition. With the definition we suggest that there is considerable uncertainty about future energy markets and technologies; and that R&D could lead to an option(s), that is not necessarily a fully developed technology, that has value. The NRC definition is narrower and states that options are fully developed technologies that could be deployed, but for existing economic or policy conditions are not likely to be favorable for their commercialization.

Thus, in the definition we suggest, the reference case itself might be improbable. This uncertainty could be about: whether the R&D will lead to some commercialized product; the market penetration not only of this product but also of the whole category of similar products; and the many macroeconomic, policy, and regulatory possibilities.

With this approach, there is no expected prospective benefit, only option benefits (in addition to any realized benefits and knowledge benefits). The definition of option benefits is generalized to include all possible scenarios, not just the unlikely ones.

6.1.2 Projected Baseline

To estimate the prospective benefits of a government program, we suggest two key steps. The first step is to calculate the benefits of the technology associated with that program. The second step is to calculate the portion of these benefits that can be attributed to the government program.

The baseline is the case without the government R&D that would help develop the technology in question. The baseline is the condition of the energy market, environmental impacts, and energy security that would exist, absent this technology.

Each of the following alternatives seeks to establish the baseline set of conditions, to which the benefits of the technology under consideration would be viewed as an incremental addition. These benefits could be thought of as the difference between the state of the economic, environmental and security conditions with the technology, versus that without the technology, but with some level of "autonomous" technical improvements.

For the retrospective case, the NRC study took the next-best alternative as the baseline. For the prospective case, we suggest that at least three alternative approaches be considered:

(a) Use the National Energy Modeling System (NEMS), or other DOE model's, reference case;

(b) Use the base case of another model that focuses more on the type of technology and/or part of the energy market under consideration; or

(c) Use a hypothetical next-best alternative, without resorting to using a forecasting model.

Each of these alternatives is discussed in turn.

(a) NEMS Reference Case as the Projected Baseline

The reference case forecast of the Energy Information Administration's (EIA's) NEMS model could be used as the projected baseline. This approach has the advantage that EIA is independent of the other offices such as EERE, FE, NE, and SC. Thus, there is an element of "neutrality" in EIA's projections. The NEMS model is a comprehensive, large-scale model of the supply, transportation, and use of energy in the U.S.

NEMS produces forecasts of the market penetration, use, and energy consumption of alternative technologies across all major supply and end-use sectors. The specific values used for NEMS' input parameters reflect implicit and in some cases explicit assumptions about macroeconomic conditions, as well as regulatory and policy changes*. NEMS also assumes technical change (i.e., improvement) in energy technologies.* As such, this projected baseline implicitly includes the next-best alternative. Thus, when using NEMS, users should first be aware of these assumptions.

In particular, users should review and evaluate assumptions made about the technological changes in the energy sector, and especially about technologies similar to or even encompassing the technology under consideration. If this technology is a very small component of the market, then it might be reasonable to assume that the technology would have little impact on NEMS' assumptions about technical change and the resulting prices, market penetrations, and other baseline conditions, regardless of whether the technology was commercialized and deployed. In this case, the reference case forecast can be used as given for the projected baseline. However, if the technology is one that could have a major impact on the market, then it is important to adjust the inputs for the NEMS reference case NEMS to *not include* the technology, but rather the next-best alternative.

(b) Reference Case of A Model Other Than NEMS

An alternative to using NEMS is to use another model(s) that might have more detail about, or is in some other way better suited to assessing, the technology under consideration. An advantage of this approach is that the alternative model might very well have a more accurate representation of the technology in question, as well as of the market and other conditions important to this technology. The alternative model(s) could, for example, include MARKAL and consumer choice functions that depend not only the relative prices of alternative technologies but on other attributes which are important to consumers and which affect their purchase decisions. Data from both retrospective and experiment studies could be used to identify and estimate the parameters of these models.

The use of such a model might be a more "formal" way of implementing the third alternative approach below. A major disadvantage of this approach, on the other hand, is that there would be no uniformity among baselines used to assess alternative technologies

This approach has both advantages and disadvantages. For example, there is no uniformity among energy sectors and technologies in the baseline conditions. On the other hand, greater attention might be given to the specific technology and market under consideration.

If this approach were to be used, we suggest that the key macroeconomic and other assumptions could be as consistent as possible with those in the NEMS reference case. Users might want to "calibrate" this other model against NEMS. However, clearly, there will be differences between the two models.

(c) Hypothetical, Next-Best Alternative

This approach is analogous to the one used in the NRC's retrospective study. A hypothetical, next-best technology is posited to develop, in the absence of any government R&D. The energy efficiency, emissions, security-related attributes, and other important impacts of technological development of the next-best alternative must be specified; and the technology in question then compared to this alternative.

The next-best alternative could be defined as a hypothetical composite of several alternatives that are assumed to have significant shares of the market in which the technology competes. The attributes of the next-best alternative would then be a weighted-average of the alternatives' energy efficiencies and other attributes. Perhaps the simplest method of characterizing the next-best alternative this way is to assume a straight-line average percentage improvement in technical performance for the energy sector.

The advantage of this its approach is its simplicity. The disadvantage is that it might be rather ad hoc and inconsistent with other DOE projections, including their underlying macroeconomic, regulatory and policy assumptions.

6.1.3 Government Impact

Given some estimate of the benefits of an energy technology, relative to the baseline, a separate but related issue is that of estimating the relative contribution of the government R&D program to the total benefits of the technology.

The benefits of a technology are not solely attributable to DOE. In most cases, to bring a technology to market, DOE, industry, and other organizations contribute to the outcome. The NRC study found no reliable way to quantify the DOE contribution in most cases, and it regards that doing so remains a major challenge for future research (NRC 2001). Thus, the NRC study did not apportion shares of benefits between DOE and industry. Hence, the net benefits in the NRC report should be interpreted as the benefits *associated* with the respective technology programs rather than the benefits that can be completely attributed to these programs.

We use Figure 1 to discuss this issue. In this hypothetical case, DOE R&D takes place early in the technology development process. Some basic scientific research might be involved. Then industry, either through a cooperative research and development agreement (CRADA) with DOE or independently, invests to develop a product using the technology. If product development is successful and the market appears promising, industry then begins commercialization of the product. Finally, production begins. The firm must invest in capital and pay for labor and other costs of production. In return, the firm has revenues from sales of the product.

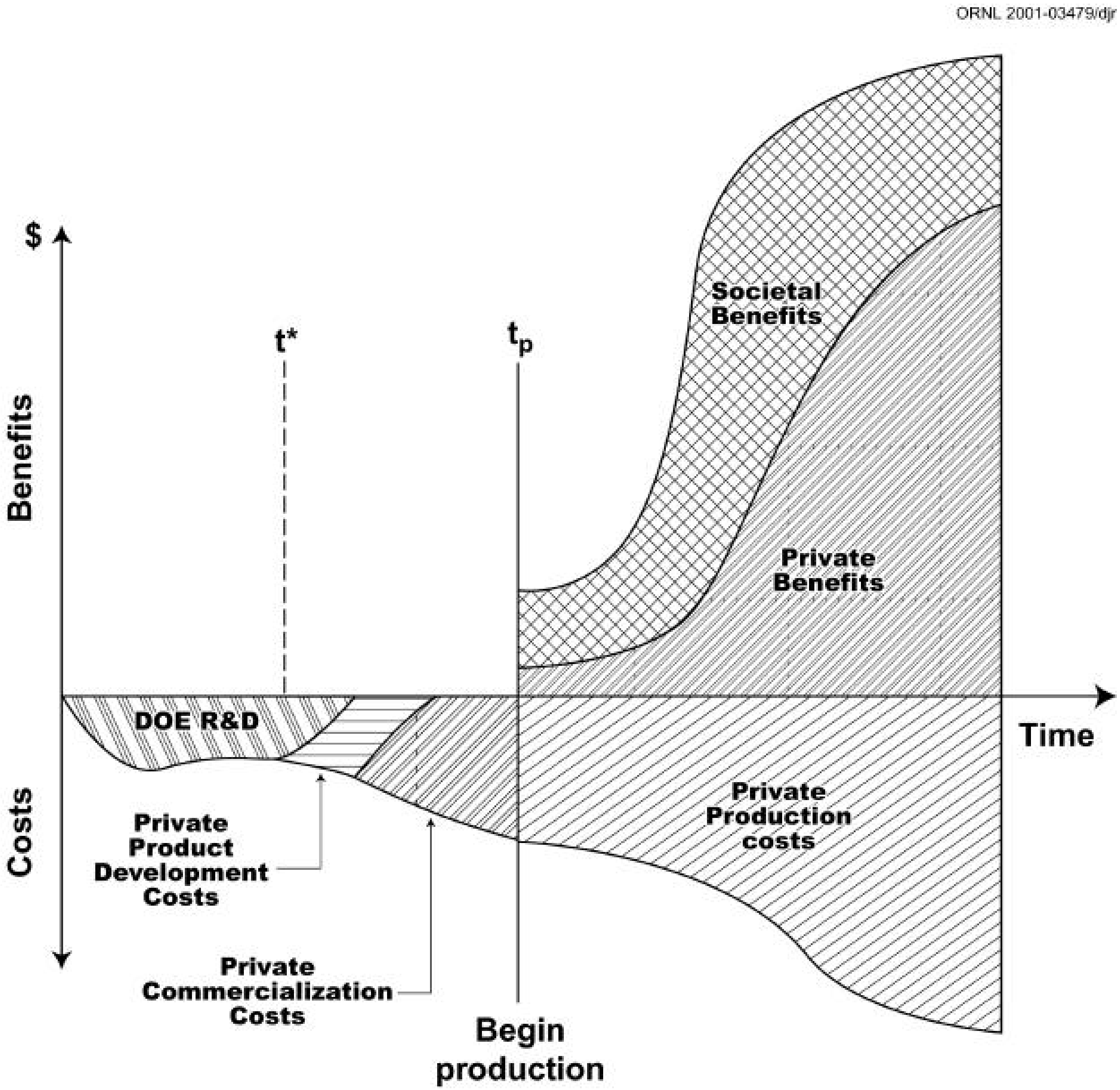

Figure 1. Benefits and Costs of a Research, Technology Development and Product Cycle

Some of the private benefits belong to the firm, reflecting revenues from the sale of the product. Much of the rest of the benefits accrue to consumers, who in this case save energy. There are also spillover benefits to other firms who improve their products by learning about the technology in question. Finally, there are other, societal benefits such as improvements in environmental quality. To attain these various benefits, investments are required from both DOE and the firm. A government program might lead to the eventual commercialization of a technology, or accelerate its introduction into market; but the private sector also plays a critical role. The conundrum is deciding how to attribute the appropriate share of these benefits to each party.

To provide a starting point for discussion at the conference, we offer the following alternative ways of characterizing the impact of the government program on a technology's overall benefits:

(a) No attempt is made to estimate the impact of the government, separate from that of the private sector and other parties.
(b) All societal benefits including the consumer benefits, plus the spillover benefits.
(c) Ratio of DOE to private sector investment.
(d) Typical equity held by initial investors.
(e) Case-by-case survey.
(f) The 5-Year Rule.

Each of these is discussed in turn.

(a) No Apportionment of Benefits

In this approach, the position taken is that it is either too difficult or impossible to separate non-additive contributions among many participants responsible for developing a technology. Thus, the benefits of a new technology would be considered as being *associated* with (but not solely the benefits of) the DOE R&D program that led to its eventual deployment.

(b) Credit DOE with the Societal Benefits Including the Consumer Benefits, Plus the Spillover Benefits

The reasoning behind this option lies in the position that the role of the public sector is only to provide societal and spillover benefits. Since a private firm generally does not invest to obtain a return on any form of societal benefit, DOE might be apportioned all of the societal benefits. This would include the consumers' surplus (the difference between what consumers were willing to pay, and what they actually paid, for a product or service), plus the spillover effects to other firms (which would need to be estimated), but none of the firm's own benefits.

(c) Ratio of DOE to Private Sector Investment.

In this alternative approach, DOE's share would be calculated by multiplying the present value of all of the net benefits, by the fraction of its R&D spending to the firms' costs (i.e., the present value of each). In this case, this fraction might be fairly small in spite of the fact that DOE's up-front spending will carry greater weight compared to the firm's discounted costs. All of the firm's production costs would be included in calculating this ratio because these expenditures are necessary for the benefits of the product to be realized.

(d) Typical Equity Held by Initial Investors

The relative value of DOE's contribution to a technology might be estimated by what its equity might be if it were a private partner in a new start-up company selling a product that uses that technology. This share could be estimated empirically – for example, the ratio of the equity held by the initial partners in technology companies, to the equity held by investors who purchase shares in the company later through initial public offerings. This calculation would take into account the relative size of the investment made by each party, compared to their equity stakes in the company.

(e) Case-by-Case Survey of Qualitative Contribution

This approach uses a qualitative assessment and classifies DOE’s contribution to the eventual successful commercialization of the technology as being either “Dominant,” “Influential,” Minimal,” or “Absent.” This assessment could be done on a case by case basis for each major program that is evaluated. Representatives from the firms that eventually designed and produced the product were asked to make an assessment on this four-point scale. Such assessments can be made for retrospective studies but appear to be problematic for prospective studies because the commercialization of the technology has not taken place, and the technology itself not yet developed.

(f) Generalization of The 5-Year Rule to a Program-by-Program Basis

The 5-Year Rule adopted by the NRC study assumes that the private sector would lag DOE by five years, with the same level of R&D and the same outcomes, if DOE had not itself invested. We suggest that this rule could be generalized and that the impact of a government R&D program could be represented as a change in the timing of the benefits of the technology developed from that program. We further suggest that the specific time lag could be determined on a program by program basis. Just as, for example, supply curves that describe the quantity of energy services available at different prices are different for different technologies, government R&D programs will reduce the time it takes for technologies to reach market to different extents.

The 5-Year Rule was used in the NRC study to estimate the impacts of the government R&D program. Thus, rather apportion benefits to DOE according to the recipient of the benefit, as in approach (b), the 5-Year Rule calculated DOE's *incremental* impact as being the difference between the stream of net benefits associated with the technology in question, and that same stream shifted 5 years later. Figure 2 illustrates this situation.

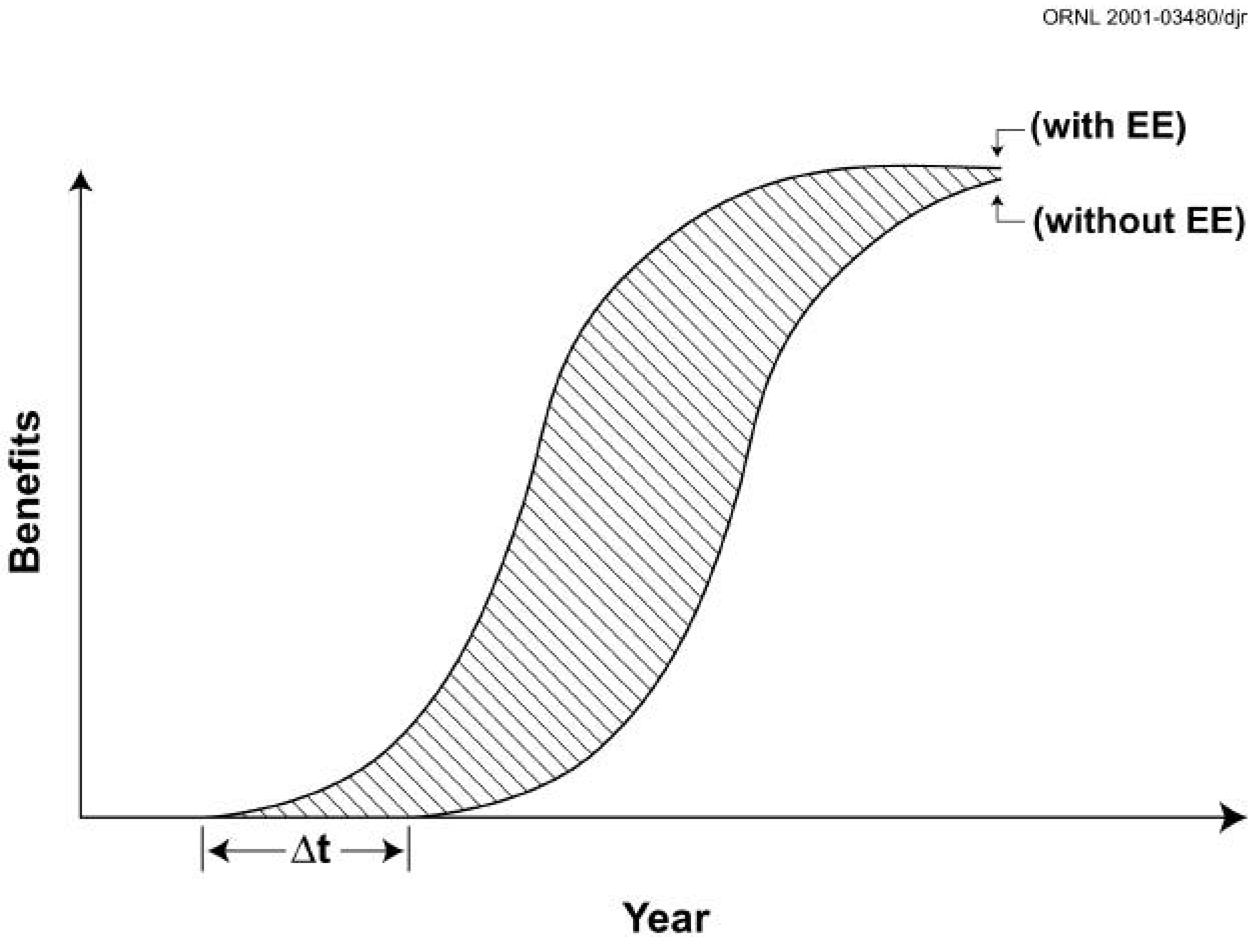

Figure 2. Illustration of the 5-Year Rule in Which the Private Sector would have Invested in Technology R&D as DOE did, Only Five Years Later. The 5-Year Rule can be used to Estimate the Contribution of DOE's R&D Program to the Benefits of the Technology Under Consideration

To consider the NRC committee's approach in more detail, we can review Laidlaw's (1997) study, one of the few on the effect of government R&D on product development cycles. Laidlaw (1997) studied the acceleration of technology development as a result of funding by the Advanced Technology Program (ATP).[16] She interviewed representatives from 28 companies that had been funded by ATP in 1991. None of the projects involved an energy efficiency technology, but all involved advanced technology development. Laidlaw (1997, Table 6) found that the companies viewed ATP's involvement to have cut their R&D cycle times in about half, which was the median and by far the most common response. The median estimate of the R&D cycle was six years so that the median reduction in the cycle was estimated to be three years.

[16] ATP is part of the National Institute of Standards and Technology (NIST) in the U.S. Department of Commerce. ATP aims to bridge the gap between research labs and the marketplace by co-funding projects to help bring technologies closer to commercialization. Companies conceive, propose, co-fund and execute the projects. ATP focuses on only those projects in which there is significant potential for national or societal gain, in addition to private gain to the company.

Thus, the time to bring the product to market and the time when benefits commence, from the sales of the product, was presumably reduced by three years.

This estimate of a three-year lag might be a reasonable approximation for DOE R&D programs that are at phases of their R&D cycle similar to those of the ATP projects, specifically those that need to have the gap between research labs and the marketplace bridged. For most DOE programs, however, we suggest it likely that the lag is likely to be at least the five years suggested by the NRC study.

Two reasons for this suggestion are that:

- ATP's projects are *all* with companies developing specific technologies that, for the most part, are well along in their R&D cycles. DOE's projects, on the other hand, generally involve technologies that are at earlier stages of their R&D cycle. ATP's projects are, by definition, involve specific technologies that particular companies have decided are worth investing in R&D. Many of DOE's programs, on the other hand, do not involve any private-sector participation at all. There are several possible reasons for the lack of private-sector involvement in an R&D initiative: its long time horizon, the risk in developing new technologies, uncertainty about market conditions, and the private gains being insufficient compared to the sum of the public and private benefits.

- The ATP technologies under development might have benefited from previous government research, ranging from direct support from other federal agencies to spillover knowledge from other government-supported projects. When this is the case, then is time interval would be added to the lag identified in Laidlaw's study.

Furthermore, in five of the twenty-eight ATP projects, or about 18%, the companies responded that the applied research would not even have been done, and the products would presumably not have been brought to market, without the ATP program.[17] This latter situation would likely be expected to be more prevalent with DOE-related technologies.

Thus, we suggest that the 5-Year Rule, which the NRC study adopted, could be used for certain types of DOE programs that involve technologies in the later stages of development. In some cases, for technologies that are on the verge of commercialization, a three-year lag might be more likely. In yet other cases, where research is being initiated or still at the early stages, we suggest that the lag is likely to much longer than five years -- possibly ten years or more. Finally, for a large portion of the programs, the lag is likely to be infinite, i.e., the private sector would never have undertaken the R&D.

Note that if method (e) above is used (a qualitative assessment of the relative contribution of the government program to the success of the technology in question), in conjunction with the 5-year rule, then this might be a double "discounting" of the government impact. If so, only one method should be used, not both.

[17] These five cases were obviously not included in calculating the average lag-time above.

6.2 OPTION VALUE

In this section, we discuss building on the option concept as introduced in the NRC report (refer to Section 5.1). Options provide discretionary choices to deal with deviations from planned scenarios.

In a <u>prospective</u> sense, there could be option value to R&D on technologies that are not being developed *primarily* to enter the market under the most likely conditions, but that would provide economically viable solutions under alternative plausible conditions. These plausible futures are generally of energy, environmental, security or other policy concern. Physical or intellectual assets (not necessary fully developed technologies as defined in the NRC study) that might be deployed in the future (not just under improbable conditions) may also contain significant option value. In this sense, options provide insurance in the face of market uncertainties, yet retain the ability to capture the upside benefits should improbably scenarios be realized.

In a <u>retrospective</u> sense, technologies that are already developed, but that are unlikely to be commercialized under current or anticipated market conditions, may yet contain option value. This value is derived from the uncertainty surrounding future market conditions. These technologies might have been developed to enter the market but did not do so because of changes in conditions -- the technologies remain available for the market in the future should conditions change to make them commercially viable. For example, carbon sequestration technologies could be options whose value might be realized if new regulations or trading of carbon emission permits take effect.

Often, a research line is pursued because it has limited, but important, expected benefits through niche market applications, but would be expected to have much wider market applications under some alternative futures, e.g., an oil disruption. While option values can persist after the research is completed (often referred to as backstop or shelf technologies), the value of the option will change as we move further into the future and more certain about whether the technology application is economically viable.

R&D can be considered as investments in options that provide opportunities to realize benefits, in the event of alternative future events. In addition to the option to commercialize, R&D investments contain a host of other investment timing options. At each stage, as new information becomes available about the probabilities of different outcomes, choices can be made regarding continuation of the research, abandoning the research, mothballing the research, etc.

This discussion implies that there are at least four alternative, but related, approaches to considering option value:

(a) The expected prospective benefits calculation is retained. If feasible, the calculated value could also be weighted by the probability of the reference case occurring, and real options methods could be used to calculate an option value for all other scenarios. If feasible, the calculated value could be weighted by one minus the probability of the reference case occurring; [this is consistent with alternative (a) for defining expected prospective benefits in Section 6.1.1].

(b) Expected net present value calculation for prospective benefits, using a Monte Carlo consideration of the probabilities of various scenarios occurring; the benefits of the technology are considered under a range of scenarios, weighted by the probabilities of their occurring; in this case, there would be no separate option benefit or option column in the benefits matrix; the uncertainty in the projections would be reflected in the "confidence bands" that arise from Monte Carlo sensitivity analyses; [this is consistent with alternative (b) for defining expected prospective benefits in Section 6.1.1];

(c) Numerical valuation based on application of methods developed for "real options;" the option valuation encompasses all scenarios so that there is no expected prospective benefits column in the benefits matrix; [this is consistent with alternative (c) for defining expected prospective benefits in Section 6.1.1]; or

(d) Qualitative assessment of the option value of technologies that are fully developed, that are unlikely to be commercialized under the most likely scenario, but that might enter the market under reasonably plausible economic or policy conditions; the prospective benefits column in the benefits framework is retained and these benefits are calculated for the technology under the reference case scenario.

Alternative (b) is a straightforward extension of the traditional discounted cash flow analysis currently used in, for example, NRC's calculation of the retrospective realized benefits, to account for the probabilities of alternative future scenarios being realized. Alternative (a) is a hybrid of (b) and (c). Below, we describe (d) and (c) in Sections 6.2.1 and 6.2.2, respectively.

6.2.1 The Option Concept as Described in the NRC Study

The NRC study defined options as technologies that are fully developed, that are unlikely to be commercialized under the most likely scenario, but that might enter the market under reasonably plausible economic or policy conditions. If these conditions are undesirable from a social and financial standpoint, then the options can be considered as a form of insurance. This description evokes the concept of a “backstop technology” that could provide some “insurance” because it would be in plentiful supply if energy prices rise to the level at which it can be used.

Technologies might have an option benefit prospectively if they are intentionally being developed, not to enter the market under forecasted conditions, but for the purpose of having an option available if conditions plausibly change. It is unlikely, however, that an R&D program would be funded if it were projected to "fail" under the most likely scenario.

Another benefit of options is that they might reduce or at least limit the prices of competing technologies. This effect is clear-cut with backstop technologies. They can be included in a supply curve that describes the total quantity (e.g., of an energy service) that is available as a function of price.

Technologies may also have option values retrospectively, as defined in the NRC study. In this case, these technologies were originally developed to enter the market but did not because of changes in conditions. The technologies are available for the market in the future should conditions change to make them commercially viable. Although the NRC study considered the option value of R&D to be possibly significant in some programs, it did not apply a quantitative method to estimate this value.

6.2.2 Applying Real Options Theory to R&D Investments

R&D can be considered as investments in options that provide opportunities to realize benefits, in the event of alternative future events. The real option approach stems from the finance literature on options, though real options are non-financial and have important differences from financial options such as stock options (Boer 2002):

- Real options often depend on the situation and have limited liquidity;
- Real options frequently do not have a fixed "strike price" at which they can be "exercised" or deployed;
- Real options frequently do not have an expiration date, though their value can deteriorate over time; and
- Transaction costs involved in real options are different in nature from those for financial options.

Valuation methods that have been developed extensively in the financial options literature may be adapted to value R&D investment alternatives under uncertainty. Schimelpfennig (1995) and Davis and Owens (2001) provide application of this theory to renewable energy. Schimelpfennig (1995) noted that option value represents the value of flexibility to use or discard new technologies. Davis and Owens (2001) use real option pricing techniques to estimate the value of renewable electric technologies in the face of uncertain fossil-fuel prices. Faiz, Hamm, and Mathews have applied real options methods to valuing high-risk energy alternatives and/or to R&D.

The value of the option, or premium, is essentially equivalent to the contingency funds that would have to be kept on hand to address an eventuality, discounted by the risk of it actually occurring, taking into account all plausible outcomes. An option can provide insurance against an adverse outcome while leaving open the possibility of capturing the upside economic, environmental and/or security benefits.

Investment to create options need not be directed only at insuring against *adverse* outcomes, or at only the most unlikely scenarios. According to its proponents, the option approach is more suitable than the traditional discounted cash flow approach when there is considerable uncertainty about the future.

To calculate the value of the R&D option, one must set values for:

- Amount of the R&D investment, for which the corresponding value of the option is to be calculated, as well as some estimate of the technology outcomes that result from the R&D;

- Degree of uncertainty about the costs to provide energy services using the technology in question, as a function of R&D;

- Degree of uncertainty about the costs to provide energy services using competing technologies, i.e., degree of uncertainty of the projected baseline prices; and

- Degree of technical uncertainty (risk) about the cost of bringing the technology to market.

Then, computational algorithms can be used to derive numerical results.

Developing these input data is a real challenge, especially when done for the first time. The uncertainties can be expressed "continuously" using probability density functions, or "discretely" using a few scenarios. Much of the real options literature uses continuous representations of uncertainty over the range of relevant future market factors. On the other hand, scenario analysis is frequently more intuitively appealing. It is a well-established approach to planning that allows individuals to assign their own views about the probabilities associated with various scenarios.

If the real option approach were to be adopted, then it could used in place of, or at least complement, the traditional discounted cash flow approach used to estimate expected prospective benefits, which was described in Section 6.1.1(a). The scenarios implicitly considered in option valuation could encompass the reference case used to calculate the expected prospective benefits. In this case, the expected prospective benefits and option benefits would be combined into one column called option benefits.

Alternatively, we suggest that the real option approach could be used for all scenarios except for the expected prospective benefits. This approach is likely more appealing for energy R&D planning because the concept of a reference case is a familiar and broadly accepted approach.

6.3 KNOWLEDGE VALUE

R&D produces scientific knowledge. It might be either specific information or general insight about a field of study. Knowledge benefits tend to be the earliest benefits of the R&D process. In fact, the main mission of science programs is the "creation" of new knowledge. Even technology-oriented R&D programs that fail might contribute to the state of knowledge about the field in terms of what does not work.

Knowledge benefits are comprised of useful or potentially useful scientific knowledge and technology, that have resulted from R&D initiatives, and that are not reflected in realized or option benefits. In a prospective context, the goal of a science program is primarily to produce knowledge. In a retrospective context, whether intended or not, a program might lead to results that have commercial value and to economic, environmental, or energy security benefits.

6.3.1 Assessment of Knowledge Benefits

In this discussion, we note some common methods that are used as indicators of the benefits of knowledge. Since science programs have no immediate commercial objective, the metrics for measuring the knowledge created by these programs should be different from those developed for technology or applied research programs.

The eventual, longer-term outcomes of science are exceedingly difficult to project. Thus, the literature on science performance measures has focused more on methods for measuring outputs of science programs:

- Accomplishment of project or program milestones
- Peer review of programs' contribution to knowledge
- Bibliometric methods.

Bibliometrics

The first two categories are rather straightforward and we focus on *bibliometric* methods. Bibliometrics refers to measures of scientific and technical outputs from science, their publications in scientific and technical journals, and the indexing of citations by other scientists in these journals. Bibliometric methods count the number of publications and other outputs of knowledge transfer or use:

- Publications
- Citations
- Patents
- Patent citations.

For example, Narin (2001) used data from the U.S. Patent System that contains information on patents granted to both U.S. and foreign inventors. The number of patents indicates the technological output. The citation of patents is a measure of the quality of the patents and their impact. Additional indicators imply some of the benefit of this knowledge:

- Current Impact Index. This index provides a normalized measure of the impact that an earlier set of patents is having on technology appearing in the current year -- essentially a patent citation measure. The method considers how frequently other patents are cited in patents granted in a current year.

- Science linkage. This method counts the number of times a patent cites scientific papers or similar research publications. This measure indicates how strongly a patent has relied on fundamental scientific research.

- Technology-cycle time. This index is the median age of patents cited on the front page of a U.S. patent document. This measure indicates the speed of innovation in a company or industry. Typical cycle times might be about ten years.

Major advantages of these indicators are that they are conceptually straightforward to explain, and they have been implemented and used. Limitations of these methods are that: published articles are only one measure of scientific output (technical reports might be important as well); citations measure influence, not necessarily quality; and authors who inordinately cite themselves and "friends" bias any citation indicator.

Process-Outcome Metrics

Process-outcome metrics are based on models of the stages of an innovation process (Geisler). Such models typically have four categories of outputs:

(1) immediate or direct outputs such as publications and patents, which are usually the output of scientists and researchers, and their organizations;

(2) intermediate outputs such as new products, materials or methods that are usually the output of companies that have developed these products from the technology or scientific knowledge of either their own scientists or others;

(3) pre-ultimate output, or intermediate outcome, which are products and services deployed by society or an economy (e.g., widespread commercialization and deployment of a technology); and

(4) ultimate outcome, which indicates quality of life -- such as economic, environmental, and security benefits.

To assess the contribution of knowledge to these ultimate outcomes, it might be possible to construct models of the process linkages beginning with the direct outputs and ending with the ultimate outcomes. Such models would also serve the purpose of describing the relationships between the near-term milestones of R&D programs to their ultimate, longer-term goals.

Prospective Analysis

The challenge of prospective analysis is that the future is of course unknown. The bibliometric methods discussed above are generally limited to retrospective analysis. It would be interesting to assess statistically whether certain characteristics of research and the knowledge it creates tend to lead to better bibliometric results. Furthermore, it would be interesting to assess whether it would be possible to identify general attributes of scientific research that can be linked to current-impact, science-linkage, and technology cycle-time indicators that might be used in conjunction with process-outcome models of the science, innovation, commercialization, and deployment process.

For the time being, however, it would appear that prospective analysis must rely on expert panels' identification of high-priority areas of research, and peer-level assessments of research proposals. Peer-review methods be adapted and used as the primary method for assessing the prospective benefits of scientific programs. An example might be the use of Delphi types of processes to develop assessments of the prospective knowledge-related benefits of various science programs. GPRA-like projections are generally much different from typical technical peer reviews, though, so that peer reviews for the purpose of GPRA-related requirements would need to crafted to address these types of needs.

6.3.2 Spillovers

The organization creating the knowledge might retain intellectual property rights to it, but knowledge can spillover to other organizations, firms and to the market at large. Jaffe (1996) identifies the following types of spillovers –

- Knowledge spillover. Sometimes, knowledge created by one organization can be used by another without any compensation, or with compensation less than the value of the knowledge. Economic exploitation of knowledge requires the sale or productive use of a new commercial product or process that somehow embodies some of that knowledge (Jaffe 1996, p.5).

- Market spillover. These spillovers result when the operation or activity of one firm in the market causes some of the benefit to flow to other market participants, other than the innovating organization.

- Network spillovers. These result when the economic value of a new technology depends greatly on the development of a set of related technologies. An example is certain types of alternative-fuel vehicles whose success in the market will depend greatly on there being a geographically distributed re-fueling infrastructure.

The econometric findings that R&D leads to macroeconomic growth on a large geographic scale likely reflect these sorts of spillover phenomena, certainly the market and network spillovers (see also, Section 6.4.2). Such spillovers might be a significant portion of the overall benefits of R&D.

Prospective estimates of spillover effects would need to rely on statistical and econometric findings of retrospective studies.

6.4 SECURITY, ECONOMIC, AND ENVIRONMENTAL BENEFITS

6.4.1 Security Benefits

Energy security in the past has typically focused on vulnerability to oil imports in a cartel market. Since September 11, 2001, the vulnerability of energy infrastructure and systems to catastrophic disruptions has become a greater concern than previously considered. In addition to oil security and energy infrastructure security, energy security includes electric power reliability.

In this white paper, energy security refers to the adequate and reliable delivery of energy products and services with reasonably stable prices in a competitive market. This definition is more general than the one used by the NRC committee. The NRC study's definition of security benefits refers to changes in the probability or severity of abnormal energy- related events that would adversely impact the overall economy, public health and safety, or the environment. The definition suggested here includes these changes, but also includes oil dependence and the costs of maintaining electric power reliability under "normal" conditions.

<u>Security of Energy Infrastructure and Systems</u>

There has been much more concern since "9/11" about the risks of major damage and disruption to domestic energy infrastructure and systems. Among the more prominent public concerns are nuclear power plants, the electric power grid, natural gas pipelines, oil pipelines and refineries, and large hydropower dams.

Different types of energy technologies and systems can affect the vulnerability of the country's energy supply to catastrophic disruptions. For example, small-scale distributed generation reduces reliance on, and thus the risks of disruptions to, the electric power grid; nuclear technologies that inherently preclude the possibility of a melt-down would make facilities using these technologies less vulnerable; and sensors and other instrumentation that monitor facilities for intrusion would reduce the risk of attack.

We suggest that the benefits of energy R&D, that contributes to reducing these sorts of risks, might be estimated using probabilistic risk analyses of the impacts of the technologies on the following:

(a) Reduced cost of outage or disruption to users,

(d) Reduced cost of providing a given, desirable level of security (e.g., cost of security personnel and equipment),

(e) Reduced impact on an industry and on the economy region- or nationwide (e.g., estimated using economic input-output models).

Oil Security

Oil security usually refers to our (i.e., the United States') dependence on imported oil. There are three types of costs in situations in which an oil cartel is able to raise prices above competitive market prices. These costs are (Greene and Tishchishyma 2000, Greene and Leiby 1993):

(a) The economy's ability to produce is reduced because a key factor of production, oil, is more expensive than what the price would be in a competitive market,

(b) sudden disruptions to oil prices increase unemployment and reduce economic output, and

(c) oil producing nations are extracting an “economic rent” from oil consuming regions by influencing prices to a far greater degree than could be done in a competitive market.

This literature has estimated a range of values, expressed in dollars per barrel of displaced oil, for the oil-security related benefits of technologies that reduce oil consumption.

Energy security, in the context of imported oil, is primarily a transportation-sector issue. Seventy-one percent of the petroleum consumed in the U.S. is used in transportation (EIA 1998, as cited in NRC 2001). If none of the transportation technologies have been commercially used, then a retrospective analysis of these programs would find that no oil has been displaced and thus no economic benefits associated with these technologies.

A major assumption for a prospective analysis, then, is the market penetration of new technologies, from which the associated reduction in oil consumption can be calculated. Systematic methods should be developed for making these assumptions.

In addition to the market-related costs of imported oil in a cartel-dominated market, there are the military costs of ensuring reliable supply of crude oil from politically volatile regions. Some would argue that these costs would not have to be incurred if there were a competitive global oil market.

Reliability Benefits: Power-System Technologies

Several R&D programs in the power technologies area are striving to improve energy efficiency and reliability in the areas of superconductivity, energy storage (e.g., utility battery storage, superconducting magnetic energy storage), distributed generation, and transmission reliability. The benefits of electric power reliability, although widely recognized, have thus far been difficult to quantify, certainly in the rigorous manner demanded by the NRC committee’s methodological framework.

Electric power system reliability is reflected in the frequency, duration, and magnitude of adverse effects on electric supply. Reliability issues arise from "normal" as well as catastrophic (e.g., terrorist) events. The benefits of reliability are reflected in the damages that are *avoided* by having a reliable system, and in the higher rates which customers are willing to pay for more reliable power (e.g., non-interruptible-power contracts). Through additional analysis, it might be possible to estimate quantitatively various components of the benefits of electric power reliability:

(a) "Real-time energy value" – replace the measures of energy savings and their financial value (Btu's and Btu’s times *average* price, respectively), which are currently used, with a measure of financial savings that accounts for energy savings (and increases) and the *different* electricity rates at different times of the day and year;

(b) “Reduced outage costs” – the financial value of reliability as measured by the estimated reduction in customers’ outage costs; and

(c) “Reduced costs of providing reliability” – a quantitatively more important economic value of reliability than the previous one, is measured by the reduced costs of providing reliability (i.e., reduced generation costs that would in turn reduce industrial and commercial consumers' costs of doing business, as well as residential customers’ utility bills).

6.4.2 Economic Benefits

The NRC committee defined economic net benefits to be based on changes in the total market value of goods and services that can be produced in the U.S. economy under normal market conditions, absent energy disruptions or other energy shocks (NRC 2001). As noted by the committee, the net benefits must be estimated relative to the benefits that could have been attained with the next-best alternative, and by subtracting the incremental costs relative to the alternative.

There might be other important economic benefits, in addition to the energy-savings benefits that were the focus of the NRC study. In this discussion, we identify two: consumer benefits other than energy savings and macroeconomic benefits.

<u>Consumer Benefits Other than Energy Savings</u>

New technologies, such as in the area of commercial lighting systems, might provide benefits other than energy savings. For example, the quality of light they provide might enhance worker productivity. More analysis is needed in this area, and more generally in developing and applying alternative ways of estimating quantitatively consumer benefits (Jones and Bjornstad 2001). In this context, Austin and Macauley (2000) have estimated future consumer benefits from government-funded innovation by estimating the “consumers surplus” from innovation.

<u>Macroeconomic Benefits</u>

Several econometric studies have identified statistically significant relationships between R&D and economic growth. For example, Martin et al. (1997) have developed a framework for estimating the national economic benefits of government funding of medical technology development. Lev used an econometric model with operating income as the output measure of the payoff, and investments in physical capital and R&D as the inputs. He found significant correlation between a chemical company's R&D intensity and its return on R&D.

6.4.3 Environmental Benefits

Environmental net benefits are based, in the NRC report, on changes in the quality of the environment that have occurred, will occur, or may occur (with some non-zero probability) as a result of the technology (NRC 2001). Changes in environmental quality are often measured using some indicator such as the net change in emissions of a pollutant. These benefits are typically not directly measurable by market prices but by some measure of the value individuals are willing to place on these changes.

Environmental Impacts with Market Value

Markets for trading some types of emissions are being introduced, however, and these markets provide direct evidence of the prices paid to obtain rights to emit these pollutants. However, these prices are good indicators of the "value" of these pollutants only if the marginal cost of controlling the pollutants equals the marginal benefit of reducing their damages.

Some environmental damages, such as reduced crop yields as a result of exposure to ozone, have a direct economic impact as well in terms of the value of the crop loss.

Non-Market Environmental Impacts

For non-market environmental impacts, studies in the environmental economics literature have developed methods to estimate quantitatively the damages associated with several pollutants. Even though markets generally do not exist for environmental quality, per se, estimates of environmental damages can be expressed in economic terms using the willingness-to-pay paradigm (as applied by Ottinger et al. 1990, ORNL/RFF 1994, EC 1996-2001, Pearce et al. 1996, Tol 1999). These studies allow us to estimate some of the environmental benefits of various technology options. The values are not universally accepted but they can and have been used.

Ecosystem Impacts

Economists and environmental scientists still frequently disagree on how to quantify other types of environmental impacts, particularly those to ecosystems. These impacts are generally site-specific so that it is difficult to gauge the benefits of R&D programs on reducing these sorts of impacts. On the other hand, it might be possible to generalize that certain types of technologies have more significant impacts on ecosystems than other technologies. To the extent that these sorts of impacts are valued (though not necessarily in monetary terms), some systematic method would be useful for gauging their relative importance, if only in subjective qualitative terms. Thus, one might propose a qualitative scale that reflects the severity of different types of ecosystem impacts.

Such a measure might be used in conjunction with estimates of the value of the services provided by ecological systems. For example, values expressed in $/hectares per year might be used for open-ocean, coastal, forest, grass/rangeland, wetland, lakes/rivers, desert, tundra, and ice/rock biomes.[18] Technology impacts might then be subjectively evaluated, and expressed in

[18] Robert Constanza, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton, and Marjan van den Belt (1997) "The Value of the World's Ecosystem Services and Natural Capital," *Nature*, vol. 387, 15 May 1997, pp. 253-260.

terms of this measure. Other thinking on the value of natural systems considers the current economic paradigm to be flawed in terms of its valuing of ecosystems.[19]

7. CONSIDERATIONS IN IMPLEMENTING A FRAMEWORK AND METHODS

Regardless of which framework and methods are identified, there are several important considerations that should be kept in mind as these methods are identified, discussed, and assessed.

7.1 DATA CONSIDERATIONS

One of the most important considerations is the availability of data. The data required for the calculations should be available and should not require massive effort to collect, solely for the purpose of estimating the benefits of R&D programs.

Another data consideration is that baseline forecasts and other assumptions should, if possible, be consistent with "official" DOE forecasts, usually from EIA. This data source would provide a reasonably consistent set of baseline assumptions. If EIA sources of information do not exist or are inadequate for the purpose at hand, then the assumptions and projections of other models or baselines used should be checked against the corresponding parameters in the EIA models.

Inevitably, subjective assessments will have to be made. For example, the market penetration projections are key to estimating their possible benefits. If these projections must be made through subjective assessments, then they could be made, or at least reviewed, by a peer group whose members have an arms-length relationship with DOE, to the extent possible. Program managers are knowledgeable about the technologies being researched by their programs. But they are obviously biased and their projections might be questioned. Reviews of program managers/ projections by an independent party are a good check on the reasonableness, if not likely accuracy, of the projections. An even better approach might be to use expert panels whose members do not have a conflict of interest.

7.2 PROCESS CONSIDERATIONS

There are several aspects to be considered in estimating benefits and other performance measures that might improve their cost-effectiveness:

(a) Output-outcome process. Shorter-term, direct outputs of an R&D program are usually of greater immediate interest to R&D program managers because they can relate to, and control, these outputs much more than their ultimate outcomes. As discussed in Section 6.3.1, descriptions (or what might be termed conceptual models) of the possible process by which outputs might become outcomes could provide roadmaps to help design R&D programs better.

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[19] Charles Hall, Dietmar Lindeberger, Reiner Kummel, Timm Kroeger, and Wolfgang Eichhorn (2001) "The Need to Reintegrate the Natural Sciences with Economics," *BioScience*, vol. 51, no. 8, pp. 663-673.

(b) If requests for information from R&D programs are such that they can provide that information in a consistent, uniform way, then this is likely to be more cost-effective than multiple requests of different variations of similar information. Also, computer software that not only has an easy-to-use interface but that interpolates input data, would again reduce the burden on program managers (e.g., software that interpolates annual market penetration based on a projection of the ultimate long-term market penetration and the time to attain that level).

(c) If the measures and the ways in which they are calculated are transparent and easy to communicate, even though the details of the mathematics might not, then the measures are likely to be better understood and received by their users.

(d) It is unnecessary, and sometimes it cannot be justified, to develop quantitative estimates of all of the benefits. Sometimes, the quality and imprecision of input data might not justify detailed numerical results -- order of magnitude estimates might very well be better in these cases. In other cases, the very nature of the benefits in terms of their social or ecological impacts might inherently preclude their being quantitatively estimated. In such situations, these benefits might be just as, or even more, important than other types of benefits that can be quantified.

7.3 ASSESSING A PORTFOLIO OF R&D PROGRAMS AS OPPOSED TO JUST INDIVIDUAL PROJECTS

In conducting its retrospective review, the NRC was evaluating individual projects - or in some cases - programs. Looking both retrospectively as well as prospectively, the NRC recognized that the portfolio concept was very important to properly evaluate the benefits from an overall research program. The portfolio concept has many attributes- ranging from the types of research that should be conducted- from basic to applied - to the time frames expected for the research results, and other variables.

The NRC recognized that a portfolio of many projects would have both failures as well as unanticipated successes. The NRC did not formally assess the overall appropriateness of the DOE portfolio, as this was not within the scope of the task assigned.

The NRC matrix for the individual programs did not evaluate some of the features of a balanced portfolio, such as the time frame for projects. The issue of how individual project benefit assessments should be used in constructing a portfolio benefit assessment needs to be addressed.

7.4 ASSESSING MULTI-YEAR PROJECTS OR PROGRAMS AS OPPOSED TO AN INDIVIDUAL YEAR'S BUDGET REQUEST FOR A PROJECT

The NRC evaluation was retrospective, so it evaluated many years worth of research that were part of ongoing programs. Using this framework prospectively presents more challenge. Most programs are multi- year, and an individual year’s budget request may include out- year projections of costs, benefits and milestones.

The question if one should assess - and if so how – any benefits of one year of a program remains. Does achieving interim milestones for a multi-year project account for a benefit apart from program management? Milestones for project management and off- ramps need to be established for multi-year programs, but how these interplay with benefit assessment remains an issue to be considered.

Finally, there is the issue of how to make decisions to propose initiating a new program or to terminate an ongoing program. Should there be a threshold or payback consideration, in addition to any net present or option valuation? And for ongoing projects, how should sunk costs, benefits that depend on previous findings, and successful completion (or failure in attaining) program milestones be taken into account in decisions to continue their funding?

8. CONFERENCE FORMAT

This conference is about framework and methods, not policy positions, nor advocacy of particular technologies or science, nor viewpoints for or against government R&D. The conference will consist of plenary sessions and workshops. The plenary sessions will set the stage for the in-depth discussions that will take place in the workshops, and provide a forum for exchanging insights from these workshops. The workshops will identify methodological framework(s) for estimating the benefits of government-sponsored R&D, and the methods that could be used for estimating the individual types of benefits.

The emphasis of the discussions in the conference workshops will be on identifying the more promising and practical methods, particularly those that can be easily communicated.

Also, the role of the conference, and of this and other draft reports related to the conference, is to identify and to provide suggestions about these methods. It is not to provide recommendations or advice to DOE.

To provide some focus to the discussions, rather than a potpourri of ideas, we make clear the objectives of each session in the conference.

8.1 PLENARY SESSIONS

The plenary sessions will convey information about the objectives of the conference and the perspectives of both the U.S. Department of Energy and congressional staff members. The plenary sessions will also provide some common background information about how some DOE offices, as well as some other Federal agencies, currently estimate and/or consider the benefits of their programs in the context of GPRA and/or program planning.

In addition to providing foundation- and background-types of information, the plenary sessions will enable workshop participants to exchange the insights, developed in the four workshops, among all conference participants.

Objectives of Plenary Sessions

Session	Objectives
1. Conference Opening, Overview, Background, and Objectives	1.1 Present DOE and Congressional views on conference objectives.
2. Methods Currently Used by DOE Offices to Estimate the Benefits of Their R&D Programs	2.1 Provide summaries/overviews of methods used by energy resources and science offices in DOE.
3. Federal Perspectives on Performance Measurement	3.1 Present information on what other Federal agencies do, as well as OMB's perspectives.
4. Establishing a Starting Point for Discussion of a Methodological Framework for Defining R&D Benefits	4.1 Summarize the NAS/NRC benefits framework. 4.2 Present suggestions that build on the NAS/NRC framework.
5. Structure, Goals, and Priorities of the Workshops	5.1 Describe the structure of the workshops.
6. Summaries and Feedback on the Workshops' Discussions of a Benefits Framework	6.1 Summarize workshops' discussions.
7. Review the First Day's Workshops and Review of the Second Day of Workshops	7.1 Summarize workshops' discussions from Day 1 and provide overview for Day 2's sessions.
8. Workshop Summaries and Discussion	8.1 Summarize workshops' discussions, particularly on Day 2.
9. Next Steps and Closing Remarks	9.1 State next steps and how conference results might be used.

8.2 WORKSHOP A: PROSPECTIVE BENEFITS -- CROSS-CUTTING ISSUES

Workshop A will address issues that cut across the problems of estimating the prospective security, economic, and environmental benefits of energy technologies associated with government R&D programs. The key question is how to estimate the *"delta"* or *incremental* contribution of a government-sponsored R&D whose goal is to develop particular energy technologies. To address this question, two important issues demand special attention:

8.21 Developing a Baseline, Absent a Technology Developed in Part by a Government Program

To estimate the prospective benefits of a government program, a baseline must be established. The baseline is the case without the government effort that affected the development of the technology. It is the energy market, environmental impacts, and energy security that would exist, absent the energy technology that is to be developed through government-sponsored R&D. The task in the first part of Workshop A is to identify methodologies for developing both retrospective and prospective baselines for the market adoption of different energy technologies under the most likely scenario, absent the technology under consideration. Several questions are germane to this issue. How are plausible scenarios developed for technological progress (including that of existing technologies), economic conditions, and regulatory and policy changes; and how would these affect the projected baseline absent a government R&D program? Should alternative baselines be used to reflect uncertainty about future conditions? How does one consider the potential effects of other government-sponsored R&D programs that are being conducted when evaluating one related program? What are the different issues and potential approaches for considering these questions prospectively as contrasted with retrospectively?

8.2.2 Impact of the Government Program

Given some estimate of the benefits of an energy technology, relative to the baseline, a separate but related issue is that of estimating the relative contribution of the government R&D program to the total benefits of the technology. That is, what is the impact of the government relative to the overall beneficial outcome as a result of the technology? Typically, a government program might lead to the eventual commercialization of a technology, or accelerate its introduction into market; but the private sector also plays a critical role. Looking prospectively, this session in Workshop A will focus on identifying a method to estimate the effect of a government program – what is its impact on the innovation, development and design of a technology, and how is the market penetration of the technology be affected? Would the technology never be developed absent a government program? Does the government program just accelerate the development of the technology, and if so by how much? Does the program affect its projected market penetration – by how much? Also, how does the definition of the baseline condition affect how the impact of the government program should be calculated? Does the program have other beneficial effects and how are they weighed? How does one relate future streams of benefits to past, present, and future R&D investment? Should one measure the government's impact on the basis of individual R&D programs or across a portfolio?

Objectives of Workshop A Sessions on
Prospective Benefits -- Crosscutting Issues

Session	Objectives
A1. Framework for defining the benefits of R&D programs, and its use for GPRA and R&D planning and evaluation	A1.1 Discuss methodological framework for identifying benefits of energy R&D programs. A1.2 Identify how various "benefits" fall within this framework. A1.3 Identify benefits inadequately addressed by the framework.
A2. Defining and calculating the projected baseline on which new technologies are to be introduced	A2.1 Define the meaning of "retrospective baseline" and "projected baseline." A2.2 Identify methods for developing retrospective and prospective baselines, absent the new technology.
A3. Continued discussion of projected baseline	A3.1 Identify data sources. A3.2 Identify how to define *alternative* scenarios. A3.3 Identify issues for additional consideration.
A4. The effect of a government's R&D program on technology deployment and use	A4.1 Identify a method(s) to estimate or systematically describe the impact of a government R&D program on technology deployment and use.
A5. Continued discussion of the effect of a government's R&D program on technology deployment and use	A5.1 Identify data sources. A5.2 Identify issues for additional consideration.
A6. Using estimates of benefits in R&D program planning and evaluation	A6.1 Suggest how to use estimates of benefits and other performance measures in the planning and evaluation of R&D programs.

8.3 WORKSHOP B: OPTION VALUE

Options provide discretionary choices to deal with deviations from planned scenarios.

In a prospective sense, option value helps justify R&D in technologies that are being developed *intentionally* not to enter the market under the most likely conditions, but that would provide economically viable solutions under alternative plausible conditions. Physical or intellectual assets (not necessary fully developed technologies as defined in the NRC study) that might be deployed in the future (not just under what are now considered to be improbable conditions) may also contain significant option value. In this sense, options provide insurance in the face of market uncertainties, yet retain the ability to capture the upside benefits should improbably scenarios be realized.

In a retrospective sense, technologies that are already developed, but that are unlikely to be commercialized under current or anticipated market conditions, may yet contain option value. This value is derived from the uncertainty surrounding future market conditions. These technologies were developed to enter the market but did not do so because of changes in conditions -- the technologies remain available for the market in the future should conditions change to make them commercially viable.

R&D can be considered as investments in options that provide opportunities to realize benefits, in the event of alternative future events. In addition to the option to commercialize, R&D investments contain a host of other investment timing options. At each stage, as new information becomes available about the probabilities of different outcomes, choices can be made regarding continuation of the research, abandoning the research, mothballing the research, etc. Consequently, R&D programs tend to have a compound (or nested) options feature and, thus, call for algorithms to compute numerical estimates for option values. Developing the probability data required as input to these models remains problematic in many cases, however, and is a continuing barrier to the use of option methods.

Workshop B will define more precisely the concept of options and will identify methodologies to evaluate the value of their benefits.

Objectives of Workshop B Sessions on
Option Valuation

Session	Objectives
B1. Framework for defining the benefits of R&D programs, and its use for GPRA and R&D planning and evaluation	B1.1 Discuss methodological framework for identifying benefits of energy R&D programs. B1.2 Identify how various "benefits" fall within this framework. B1.3 Identify benefits inadequately addressed by the framework.
B2. Definition of options and the calculation of option value	B2.1 Define "option" in the context of R&D programs. B2.2 Describe how the definition relates to retrospective and prospective benefits.
B3. Continued discussion of option value	B3.1 Identify a method(s) for calculating the value of an option in the context of an R&D program. B3.2 Identify data sources. B3.3 Identify issues for additional consideration.
B4. The baseline scenario for option-value calculations	B4.1 Define what is meant by the baseline, in the context of option valuation. B4.2 Identify methods for developing retrospective and prospective baselines, in the context of option valuation. B4.3 Identify data sources. B4.4 Identify how to define alternative scenarios. B4.5 Identify issues for additional consideration.
B5. Effect of a government's R&D programs on option value	B5.1 Identify a method(s) to estimate or systematically describe the impact of a government R&D program on option value. B5.2 Identify data sources. B5.3 Identify issues for additional consideration.
B6. Using estimates of benefits in R&D program planning and evaluation	B6.1 Suggest how to use estimates of benefits and other performance measures in the planning and evaluation of R&D programs.

8.4 WORKSHOP C: KNOWLEDGE VALUE

R&D produces scientific knowledge. It might be either specific information or general insight about a field of study. The very nature of science programs is that they have no immediate commercial objective. Even technology-oriented R&D programs that fail might contribute to the state of knowledge about the field in terms of what does not work. Workshop C will focus on how to evaluate the benefits of scientific knowledge – what indicia could be used and how could one assess them? The primary task of Workshop C is to identify methodologies to assess knowledge benefits both prospectively and retrospectively. In a prospective context, the goal of a science program is primarily to produce knowledge. In a retrospective context, whether intended or not, a program might lead to results that have commercial value and to economic, environmental, or energy security benefits. Workshop C will also address the relationship between knowledge and technology innovation.

Objectives of Workshop C Sessions on
Knowledge Valuation

Session	Objectives
C1. Framework for defining the benefits of R&D programs, and its use for GPRA and R&D planning and evaluation	C1.1 Discuss methodological framework for identifying benefits of energy R&D programs. C1.2 Identify how various "benefits" fall within this framework. C1.3 Identify benefits inadequately addressed by the framework.
C2. Definition of knowledge value and indicators	C2.1 Describe the value or benefits of knowledge.
C3. Continued discussion of knowledge value	C3.1 Identify indicators for the benefits of knowledge and a method(s) for calculating them. C3.2 Identify data sources. C3.3 Identify issues for additional consideration.
C4. The baseline scenario for knowledge-value calculations	C4.1 Define what is meant by the baseline, in the context of knowledge valuation. C4.2 Identify methods for developing retrospective and prospective baselines, in the context of knowledge valuation. C4.3 Identify data sources. C4.4 Identify how to define alternative scenarios. C4.5 Identify issues for additional consideration.
C5. Effect of a government's R&D programs on knowledge value	C5.1 Identify a method(s) to estimate or systematically describe the impact of a government R&D program on knowledge value. C5.2 Identify data sources. C5.3 Identify issues for additional consideration.
C6. Using estimates of benefits in R&D program planning and evaluation	C6.1 Suggest how to use estimates of benefits and other performance measures in the planning and evaluation of R&D programs.

8.5 WORKSHOP D: SECURITY, ECONOMIC, AND ENVIRONMENTAL BENEFITS

Energy security in the past has typically focused on vulnerability to oil imports in a cartel market. Since September 11, 2001, the vulnerability of energy infrastructure to catastrophic disruptions has become a greater concern. In general, energy security refers to the adequate and reliable delivery of energy products and services with reasonably stable prices in a competitive market. In addition to oil security and energy infrastructure security, energy security includes electric power reliability. Workshop D will focus on identifying the nature of energy security, how it can be measured and valued, and how improvements in it can be determined and evaluated. Workshop D will also address economic and environmental benefits. These latter topics have already been the subject of extensive study (e.g., global climate change). Sessions in Workshop D will identify the economic- and environmental-benefit literatures and, possibly, the range of values which could be used. These sessions will also identify other economic and environmental considerations, such as the economy-wide impacts of R&D, and suggest methods for estimating their relative value.

Objectives of Workshop D Sessions on
Security, Economic, and Environmental Benefits

Session	Objectives
D1. Framework for defining the benefits of R&D programs, and its use for GPRA and R&D planning and evaluation	D1.1 Discuss methodological framework for identifying benefits of energy R&D programs. D1.2 Identify how various "benefits" fall within this framework. D1.3 Identify benefits inadequately addressed by the framework.
D2. Security benefits of R&D on energy technologies and systems	D2.1 Define the major types of security benefits that can ultimately result from energy R&D.
D3. Continued discussion of security benefits	D3.1 Identify methods to estimate these benefits. D3.2 Identify data sources.
D4. Economic benefits of R&D on energy technologies and systems	D4.1 Define the major types of economic benefits that can ultimately result from energy R&D. D4.2 Identify methods to estimate these benefits. D4.3 Identify data sources.
D5. Environmental benefits of R&D on energy technologies and systems	D5.1 Define the major types of environmental benefits that can ultimately result from energy R&D. D5.2 Identify methods to estimate these benefits. D5.3 Identify data sources.
D6. Using estimates of benefits in R&D program planning and evaluation	D6.1 Suggest how to use estimates of benefits and other performance measures in the planning and evaluation of R&D programs.