Guide for Conducting Benefit-Cost Evaluation of Realized Impacts of Public R&D Programs

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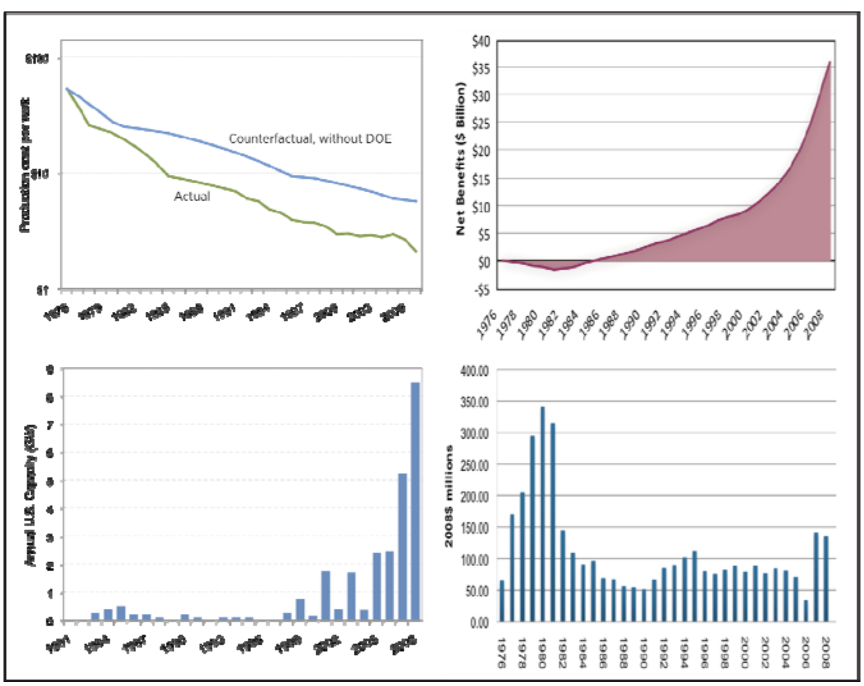

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Guide for Conducting Benefit-Cost Evaluation of Realized Impacts of Public R&D Programs

Part I. Background, Benefit-Cost Overview and Special Features

I.1 Background

This document provides guidance for evaluators who conduct impact assessments to determine the "realized" economic benefits and costs, energy, environmental benefits, and other impacts of the Office of Energy Efficiency and Renewable Energy's (EERE) R&D programs. The focus of this Guide is on realized outcomes or impacts of R&D programs actually experienced by American citizens, industry, and others. Retrospective evaluations may be contrasted to prospective evaluations that reflect expected or potential outcomes only if assumptions hold.

The retrospective approach described in this Guide is based on realized results only and the extent they can be attributed to the efforts of an R&D program. While it has been prepared specifically to guide retrospective benefit-cost analysis of EERE R&D Programs, this report may be used for similar analysis of other public R&D organizations.

Directives and guidance from the executive and legislative branches set impact evaluation expectations for EERE and other Federal programs. These are listed in Attachment 1.

EERE retrospective benefit-cost evaluations must be performed by independent professional evaluators guided by the procedures outlined in this peer-reviewed Guide.[1] Evaluators are also expected to be guided by the *Guiding Principles for Evaluators* provided by the American Evaluation Association and listed in Attachment 2. Although a degree of customization will be necessary based on the selected technologies under examination and the available data, the goal is to ensure that a basic consistency in method, approach, and convention is applied and maintained across such studies.[2]

[1] An earlier draft of this Guide was peer reviewed by external experts in November 2009. See Acknowledgements for list of members of expert panel who reviewed the earlier version of this Guide.

[2] Commissioned evaluators are expected to follow the Guide in performing EERE retrospective benefit-cost studies unless specifically exempted from its coverage. They are encouraged to read the Guide at the outset of proposing or planning an R&D impact evaluation study.

The impacts assessments covered in this Guide are intended to address the following questions of interest to managers of the Department of Energy (DOE), Congress, the general public, and other stakeholders:

1. To what extent has EERE produced energy and economic benefits relative to the next best alternative?
2. To what extent has EERE achieved environmental benefits, and enhanced energy security?
3. To what extent has EERE cultivated a knowledge-base in the research community that has impacted innovations in today's markets?
4. Would today's commercialized technologies likely have happened at the same time, and with the same scope and scale, without EERE's efforts?
5. To what extent do benefits attributable to EERE involvement exceed EERE expenditures? Was the public investment worth it?

The assessment approach outlined in this Guide produces impact results findings for the metrics defined in Table I-1. In addition to energy and economic impacts, the approach quantifies air emissions reduction, environmental health benefits (e.g., averted mortality and morbidity and other health effects, and dollars of health cost avoidance), certain energy security benefits, and knowledge creation and diffusion as reflected by patents and publications. It addresses attribution of benefits through the use of a counterfactual model which seeks to compare outcomes with what would likely have happened in the absence of the R&D program.

Directives for Evaluation of Federal Programs

Impact evaluation questions for R&D programs are motivated by the desire of program managers to efficiently and effectively manage their R&D portfolios to make the best use of public investments provided by the American people. Consistent with this aim are a host of past and recent Government directives for impact evaluation of Federal Programs. Over the past several years there have been multiple directives from the executive and legislative branches that set program evaluation expectations for federal programs, as listed in Attachment 1.

A federal energy R&D program that has determined, through systematic retrospective evaluation, its net benefits is better positioned to communicate its value to its agency leadership, Congress, stakeholders, and the public than one who lacks documented evidence. Systematic retrospective evaluation also informs program managers about possible ways to improve their programs and to position them for the future by revealing strengths and weaknesses in past performance.

The impact results quantified from the analysis <u>provide a conservative estimate</u> for three reasons:

1) The approach strives to be fully retrospective in its coverage and thereby avoids reliance on forecasted data having a higher degree of uncertainty; nevertheless, benefits in most cases are expected to continue past the cut-off year of the analysis.
2) The approach takes into account a portfolio rather than a single project; however, it includes the benefits of only a few technologies developed by a program or

subprogram while taking into account total program costs to be weighed against the partial benefits.

3) Not all benefits assessed are valued in monetary terms (e.g., the effects of Greenhouse Gases and energy security are expressed in tons of CO2 and equivalent barrels of imported oil avoided, respectively.[3])

Thus, the approach is empirical-based, and the results are more conservative than studies that (a) include forecasted effects, (b) take a project-approach rather than a portfolio-approach, (c) consider only project costs, and (d) use non-verified approaches to benefits estimation.

As such, the results determined from the analysis described in this Guide provide a **first order, lower bound estimate** of the energy, economic, environmental, security, and knowledge benefits a program has contributed to the nation. This determination of conservative impact results is to be fully described and documented in all final study reports.

The economic benefit-cost method used in evaluation studies supported by this Guide is designed to be applied to a portfolio (or cluster) of technologies, such as an entire program or subprogram. It should be noted, however, that in some cases the individual technologies selected within a cluster study may be appropriately treated as a group (e.g., a group of closely related infrastructure technologies), and in other cases each selected technology within a cluster will be more appropriately treated as an individual case study. This means that there will be some differences in the details of analyses across studies, as each study seeks to provide the most credible analysis possible for the types of technologies evaluated and the data available. This makes it possible for each individual study to stand on its own in terms of the validity of its analysis, and is to be preferred over applying an overly simplified, crude rule-of-thumb, one-size-fits-all (and less accurate) approach to benefit-cost studies.

The method presented in this Guide builds on the R&D impact assessment approach used by the National Institute of Standards and Technology (NIST),[4] and improves on the approach employed by the National Research Council (NRC) in their 2001 study *"Energy Research at DOE: Was It worth It?"* An overview of how the approach offered in this Guide makes changes to the earlier NRC approach, as well as a more detailed comparison of the two, is provided in Attachment 3.

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[3] The review panel did not think that the existing approaches to valuation of these environmental and security effects had sufficient levels of confidence for inclusion without unduly increasing the level of uncertainty in overall results. Analysis of these effects in dollar terms could be performed as a separate analysis and reported as supplemental results.

[4] NIST, through its former Advanced Technology Program (ATP), pioneered in cluster benefit-cost studies to assess portfolios of projects rather than single projects. See, for example, Thomas Pelsoci (2005, 2007), and O'Connor, Rowe, Gallaher, et al. (2007). These ATP cluster studies, however, unlike the current EERE approach, considered only economic benefits and not the other categories of benefits included in the EERE benefit-cost cluster approach.

Table I-1. Impact evaluation metrics covered in this Guide

Outcomes	Units
Economic Performance Metrics	
• Gross economic benefits	Millions or billions of dollars
• Net economic benefits (NB) (undiscounted) [1]	Millions or billions of dollars
• Net present value (NPV)[2] at 3% and 7% discount rates	Millions or billions of dollars
• Internal rate of return (IRR) on public investment [4]	Percent
• Benefit-to-cost ratio (BCR) at 3% and 7% 5	Ratio
Energy Benefits	
• Energy saved	Trillion Btu
• Renewable capacity	Mega watts (MW)
Environmental Benefits	
Air Emissions Reduction	
• Avoided carbon dioxide emissions (CO_2)	Million metric tons of CO_2 (MMTC)
• Avoided sulfur dioxide emissions (SO_2)	Tons
• Avoided nitrogen oxide (NOx)	Tons
• Avoided particulate matter emissions (PM)	Tons
Health Cost Avoidance	Tons
• Reduced morbidity (e.g., avoided respiratory symptoms, chronic bronchitis, nonfatal heart attacks) and mortality	Mortality & morbidity rates
• Health costs avoided due to reduced air emissions	Millions or billions of dollars
Energy Security Benefits	
• Displaced petroleum consumption • Natural gas displacement • Effect on energy infrastructure	Billions of gallons of gasoline equivalent (GGE); millions of cubic feet of natural gas;; barrels of imported oil equivalent (BOE) Description
Knowledge Benefits	
• Patents, publications, and other knowledge outputs and outcomes	Types and numbers of outputs, citation rates, linkages to EERE-sponsored R&D, Citation Index values, identification of notable patents, knowledge spillovers shown by linkages to other technologies and industries
Acceleration Effect (as appropriate)	Years the research achievement has advanced due to EERE R&D efforts

Notes:

[1] Net Benefits equal benefits minus costs, with no discounting applied to the cash flow.

[2] Net present value (NPV) equals the present value of the investment's net positive cash flow, minus the present value of the initial investment. A positive NPV means that benefits exceed cost by more than enough to cover all costs including the required rate of return expressed by inclusion of the discount rate in the calculations.

[3] OMB issued Circular A94 (1992) and Circular A-4 (2003) that provide directives on discount rates for federal benefit-cost analysis.

[4] Internal rate of return (IRR) is a percentage yield on an investment, found as the solution value interest rate that equates benefits and costs, resulting in a Net Present Value (NPV) of zero. The IRR is compared against the investor's minimum acceptable rate of return (also known as the hurdle rate) to ascertain the economic attractiveness of the investment. If the IRR equals or exceeds the hurdle rate, the investment is economic; if it is less than the hurdle rate, it is uneconomic.

[5] Equals the present value benefits divided by present value investment costs. A ratio greater than one means that benefits exceed costs.

As of the end of 2010, the initial draft of this Guide had been used successfully in the conduct of four EERE benefit-cost cluster studies begun in 2009, and published in 2010 and 2011. Feedback and "lessons learned" compiled from the first four benefit-cost cluster studies have been used to produce this edition of the Guide.

It is expected that, as methodological advances emerge, including those resulting from the experiences of evaluators engaged in other DOE-commissioned evaluation studies, the Guide will be updated to reflect the state-of-the-art in the conduct of impact evaluations for R&D programs. In addition to fostering best practices in impact evaluation, another objective of the Guide is to ensure that basic consistency in approach across studies is maintained.

Part I, Sections 2 and 3 of this Guide provide background on the benefit-cost method and highlight special features of this extended cluster approach. Then, in Part II, Sections 1 through 8, the Guide provides detailed step-by-step instructions to independent evaluators who are contracted to perform retrospective benefit-cost cluster studies using this methodology. Examples from the four completed studies illustrate the approach.

I.2 Overview of Traditional Economic Benefit-Cost Analysis

This section provides a general description of traditional benefit-cost method, as used to estimate the economic performance metrics in Table I-1. It is provided both to show how economic benefits and related performance metrics are derived, and to provide a point of departure for adding to the traditional benefit-cost approach the expanded features described in section I.3 of this Guide.

Dollar Benefits versus Dollar Costs

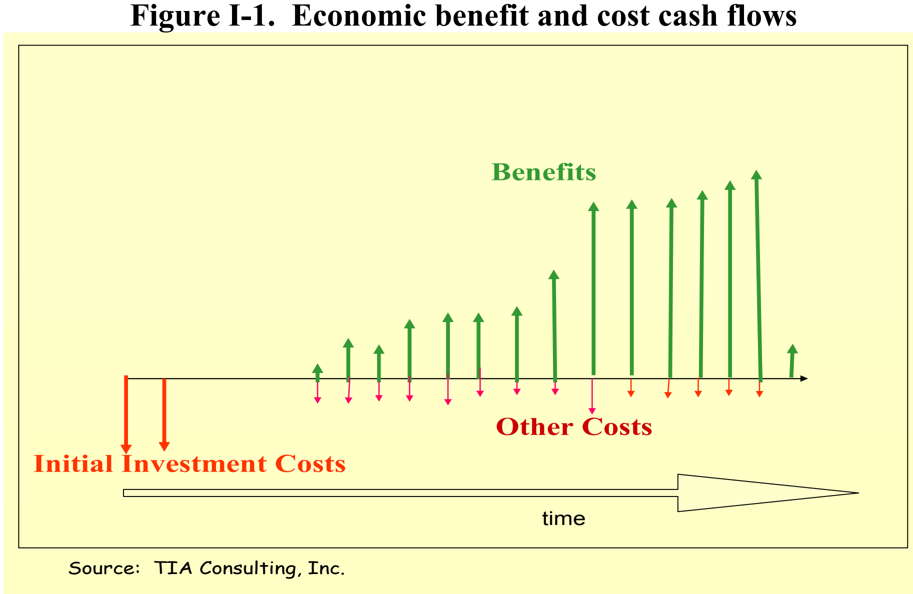
Traditional benefit-cost analysis weighs the monetary value of economic benefits of an investment against its costs to determine if it was (or, in the case of prospective analysis, is expected to be) economically worthwhile. The dollar amounts are tracked as cash flows over time in order to adjust them for the time value of money—both for changes in the purchasing power of the dollar (due to inflation or deflation) and for the real opportunity cost of capital.

The cash-flow model of Figure I-1 illustrates economic benefit and cost cash flows over time. The down-pointing arrows depict costs. The upward-pointing arrows depict benefits, which would include energy savings in the analysis of energy efficiency and renewable energy programs. Investment costs (i.e., program cluster costs) are identified as such; operating, maintenance, and repair costs in each year are typically netted out against that year's benefits.

Cash-Flow Time Adjustments

As noted above, cash flows occurring at different times must be adjusted both for changes in the purchasing power of the dollar and for the real opportunity of capital. It is possible to make the adjustments for timing differences in cash flows in **either** of the following two ways: (1) First a price deflator index can be applied to the "current" (actual) dollar amounts occurring at different times to adjust them to "constant dollars" whereby each dollar has equivalent purchasing power as of a stated base year, and then an appropriate discount formula (or derived discount factors) can be applied to the constant dollar amounts, based on an interest rate, or "discount rate," that reflects the "real" return to capital apart from changes in dollar purchasing power. (2) Both timing adjustments can be done at once by applying to the "current (actual) dollar" cash flows (without first adjusting them to constant dollars) an appropriate discount formula (or derived discount factors) based on a discount rate that reflects the "nominal" (market) return to capital.

Figure I-1. Economic benefit and cost cash flows



The result of applying either of these procedures is to express the whole of a stream of cash flows over time as either a lump-sum equivalent amount at a stated point in time, or as an equivalent uniform annual (or monthly) amount, depending on the discount formulas used. The procedure of converting a stream of cash flows over time to a time-equivalent amount at another time is often called "discounting cash flows" and the interest rate used in the discounting calculations is called the "discount rate."[5]

[5] This referenced use of "discounting" and "discount rate" is specifically within the context of capital investment analysis, as distinct from use of similar terms with different meanings in other contexts.

OMB Directives on Discounting and Discount rates

The approach for Federal benefit-cost analysis is subject to White House Office of Management and Budget (OMB) directives.[6] OMB Circular A-94, issued in 1992, directs the use of a 7% real discount rate for Federal benefit-cost analysis.[7] A more recent guidance is provided by OMB Circular A-4, issued in 2003, which pertains to benefit-cost analysis used as a tool for regulatory analysis. As Circular A-4 notes, Circular A-94 states that a real discount rate of 7% should be used in benefit-cost analysis—as an estimate of the average before-tax rate of return to private capital in the U.S. economy. This rate is an approximation of the opportunity cost of capital. Circular A-4 further notes that OMB found in a subsequent analysis that the average rate of return to capital remained near 7%. It also points out that Circular A-94 recommends using other discount rates to show the sensitivity of the estimates to the discount rate assumption, and notes that the average real rate of return on long-term government debt has averaged about 3%. It directs the use of both a 3% and a 7% real discount rate for a benefit-cost analysis conducted for regulatory purposes.

Economic Performance Measures

Use of multiple economic performance measures best meets the preferences of different audiences and help to broaden communication. There are multiple, closely related measures that are widely used to express the economic performance of an evaluated investment. Figure I-2 below summarizes three economic performance measures widely used in benefit-cost studies. These three measures are used to assess if, and to what extent, benefits attributed to a designated project, program, sub-program, or other portfolio exceeded the public investment.

(1) Net Present Value Benefits (NPV): Total present value benefits minus total present value costs.

A positive NPV means that benefits exceed cost by more than enough to cover all costs including the required rate of return expressed by inclusion of the discount rate in the calculations. The larger the NPV, the greater the extent that benefits exceed costs, and the more worthwhile is a project, other things being equal.

(Net Benefits (NB) may be shown as undiscounted (i.e., assuming a 0% required rate of return or 0% discount rate), emphasizing the effect of discounting using positive rates.) The undiscounted results is designated NB in Table I-1.

[6] OMB Circulars are available at www.whitehouse.gov/omb/circulars.
[7] OMB Circular No. A-94, Oct. 29, 1992. "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." The 1992 issue of Circular No. A-94 states that a 7% real discount rate should be used for benefit-cost analysis. In December 2008, an updated release of OMB Circular No. A-94 provided Appendix C that provided revised discount rates for Cost-Effectiveness, Lease Purchase, and Related Analyses. However, Appendix C and the cover letter accompanying the release stated that the circular applies to cost-effectiveness and lease-buy decisions, rather than benefit-cost studies. Thus, Appendix C to OMB Circular No. A-94 is not considered applicable to the benefit-cost approach given in this Guide.

(2) Benefit-to-Cost Ratio (B/C or BCR): Present value benefits (less non-investment costs[8]) divided by present value investment costs.

A ratio greater than one means that benefits exceed costs. A ratio of 10, for example, means that 10 dollars are generated in benefits on average for every one dollar of costs incurred and taking into account the required rate of return expressed by inclusion of the discount rate in the calculations.

(3) Internal rate of return (IRR): The IRR is a percentage yield found as the solution value interest rate that, when used in the appropriate discounting formulas, will equate benefits and costs, resulting in an NPV of zero. The yield is useful for comparing against a Minimum Acceptable Rate of Return (MARR) or "hurdle rate," which for Federal analyses is the discount rate, as well as against yields on other investments. If the computed IRR exceeds the MARR or hurdle rate the investment is deemed economically worthwhile. Other things being equal, the higher the IRR the more economically worthwhile the investment.[9]

Figure I-2. Economic Performance Measures

- Net Present Value Benefits (NPV): time-adjusted benefits minus costs

$$NPV = SB_{PV} - (SC_{PV} + SI_{PV})$$

where SB_{PV} = sum of present value benefits; SC_{PV} = sum of present value non-investment cost; and SI_{PV} = present value investment cost

- Benefit-to-Cost Ratio: time-adjusted benefits (net of time-adjusted non-investment costs) divided by time-adjusted investment cost

$$B/C = (SB_{PV} - SC_{PV}) / SI_{PV}$$

- Internal Rate of Return (IRR): the solution interest rate (i) that equates the values of the streams of benefits and costs over time

$$SB_{(i)} = (SC_{(i)} + SI_{(i)})$$

Source: TIA Consulting, Inc.

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[8] The ratio is sensitive to the placement of costs. Investment costs are to be placed in the denominator; operating and maintenance costs are to be subtracted from benefits in the numerator. Note that moving these costs to the denominator will change the value of the ratio.

[9] When either the B/C ratio or the IRR are used to design or size projects, these measures must be applied incrementally, because the mutually exclusive alternative with the highest B/C or IRR computed on total benefits and costs is not necessarily the one that yields the highest net benefits. However, choosing among competing designs and sizes is not the point of these benefit-cost impact studies, and the need for incremental or marginal analysis is not expected to arise.

Unlike the previous two measures, the discount rate is not used directly in the IRR calculation. Rather, the IRR is solved for by substituting an interest rate with unknown value in place of the discount rate in discounting formulas and solving for the rate for which time-adjusted benefits equal costs, i.e., for which NPV is zero. [10]

Inclusion of Other Effects

There may be economic effects that are not feasibly captured in dollar terms. If so, these are omitted in the economic performance measures. However, it has been commonly recognized in benefit-cost analysis that if other effects are potentially important to decision making, they should not be ignored, and, at a minimum, should be treated qualitatively.

Yet, because the attention of benefit-cost studies is ultimately on the economic performance measures, omitted effects are often given less attention than they deserve. Thus, evaluators have in past studies attempted to express various important effects (not usually considered economic) in monetary terms, and to include the results in computing NPV, BCR, and IRR. For example, the value of a statistical life based on willingness-to-pay was used by Ruegg and Fuller in 1984 in a benefit-cost study of fire-suppression technology, and by Butry, Brown, and Fuller in a related 2007 study. Studies of highway safety, consumer product safety, and medical treatments have variously included estimated values of life and injury or imputed such values, or have used a cost-utility analysis and quality-adjusted life years to avoid placing financial values on life. Evaluators have also in past studies assigned monetary values to a variety of intangible effects such as environment, view, and business reputation, depending on the topic of major importance. However, these approaches have been largely piecemeal, non-systematic, and controversial.

This Guide seeks to include the treatment of important, difficult-to measure, effects using a systematic, non-controversial approach, as explained below in section I.3, *Special Features of the EERE Benefit-Cost Approach*.

Federal versus Private Company Benefit-Cost Analysis

Major differences between a benefit-cost analysis performed for a company and one performed for the Federal government are perspective/scope and treatment of taxes. Regarding perspective/scope, a company typically counts as benefits and costs the cash inflows and outflows it directly realizes as a result of its investment (i.e., the *"private rate of return"*). In contrast, the Federal government typically counts all benefits and costs to the nation resulting from its action, regardless of who experiences them (i.e., the *"social rate of return" which encompasses both private returns and spillover returns*). Figure I-3 depicts in simplistic terms how private return and market and knowledge spillovers combine to produce social return.

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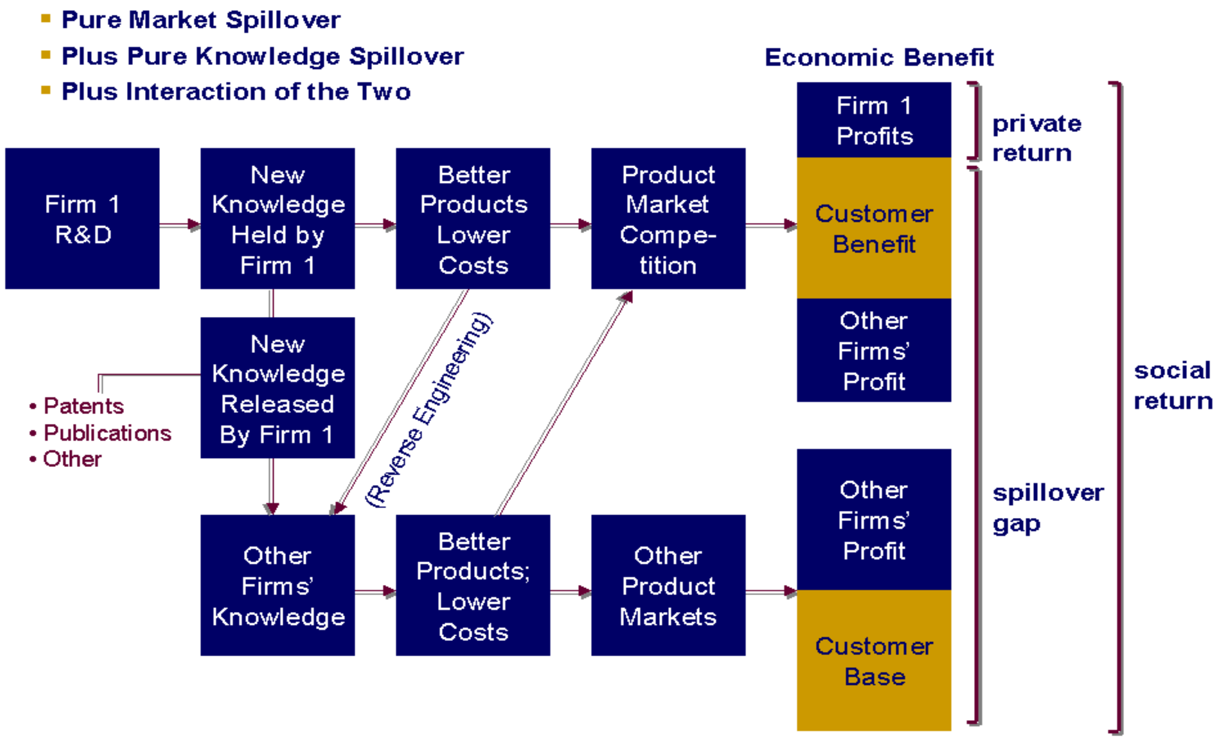
[10] There are computer algorithms available for solving for the IRR. It can also be solved manually by a series of iterations, in which trial values of i are used until a solution value is found.

Thus, Firm 1 invests in R&D, and realizes higher profits, due, say, to now having better products and lower production costs. But the situation is dynamic, and other firms may gain some of the resulting knowledge ("knowledge spillovers"), and they may compete with Firm 1 in its markets driving down prices and allowing consumers to benefit from better products at lower prices ("market spillovers"). In addition, some of these knowledge-acquiring firms may use it to produce other kinds of better or lower cost products in other markets. Some of these other benefits are captured by the producing companies; in competitive markets, some will "spill over" to consumers. Thus there is a private return to Firm 1, but there are also effects from Firm 1's actions that "spillover" to others—both to other firms and to consumers. The overall effect is the "social return."

Figure I-3. Private Return and Spillovers Combine to Produce Social Return



Source: Jaffe (1996), as discussed and modified by Ruegg and Feller (2003)

If a Federal government investment contributes to development of an improved technology, a benefit-cost analysis to assess if the Federal investment was worthwhile would take into account the net effect across all establishments and people in the nation attributed to the Federal investment. Thus, a Federal benefit-cost analysis, with its focus on social returns, typically has a much broader perspective and scope of coverage than a private-company analysis with its focus only on its own returns. An analysis of social returns is therefore typically much more complex and difficult to perform than a private-company analysis.

With regard to treatment of taxation effects, a company analysis and a Federal analysis also differ, however, this difference tends not to be as major as the differences of perspective and scope. A company typically wants to know its after-tax bottom-line return. In contrast, Federal government benefit-cost analysis is typically performed on a before-tax basis. A before-tax estimation is done because government is the recipient of Federal taxes collected, and other forms of taxes are typically not separately assessed in Federal benefit-cost analysis--unless, of course, a study is specifically aimed at assessment of the effect of specific taxes or tax incentives.

It should also be noted that it is often not necessary for a Federal benefit-cost study to estimate fully the social benefits and costs associated with a new technology to achieve its evaluation purpose. For example, to estimate if a public R&D investment in a given technology area has been worthwhile, the required analysis is of the public returns, compared to the public R& D investment cost, rather than total social benefits of having the technology versus its total social costs. To estimate the return on public investment in a specific set of wind energy technologies, for instance, it is only necessary to compute the **change** in social benefits from wind energy technologies attributed to the public investment. That is, the computation does not require that total social benefits from having all wind energy technology be computed and compared against the total social costs—a much larger task.

Use of the Mansfield's Model as a Unifying Framework for the Valuation of Economic Benefits

A model developed and applied by Professors Griliches and Mansfield, and since applied by others, has proven a useful framework for estimating social and private returns from investments in new technology.[11] Mansfield applied the model to assess social benefits of private-sector industrial innovations, finding the estimated social rate of return for a group of selected industry innovations to be substantially higher than the private rate. He concluded that there may be a substantial "spillover gap" between private and social rates of return, whereby social rates of return exceed private returns. An implication is that private R&D investment decisions, which do not take into account spillover effects, will tend to result in less investment in R&D than is optimal from the standpoint of society at large.

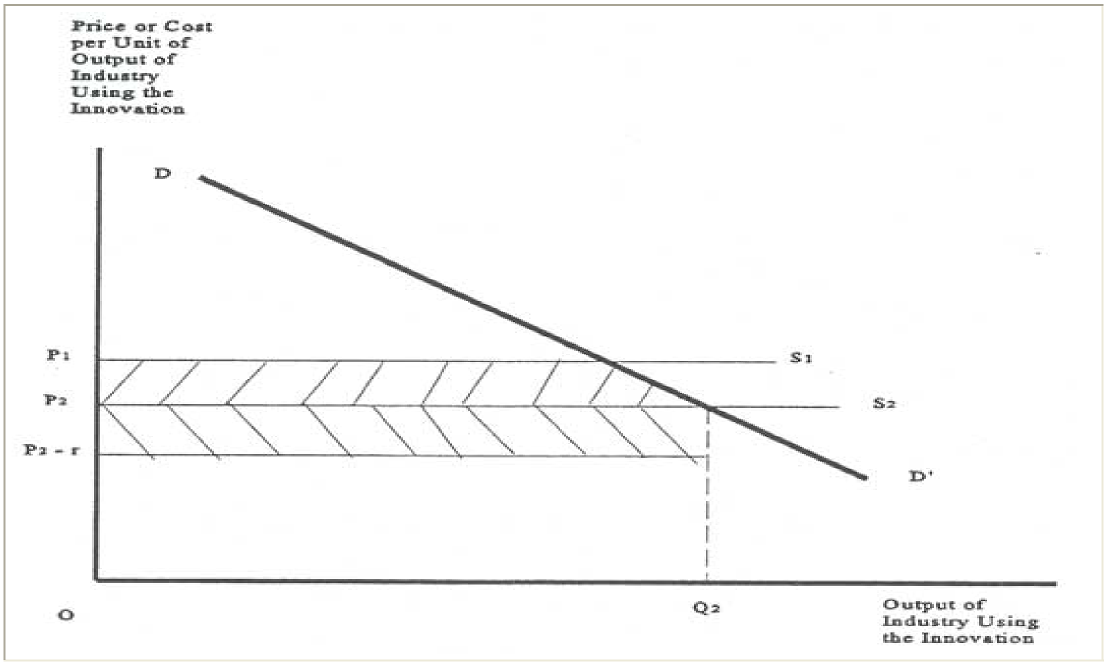
The "Griliches/Mansfield Model" has subsequently been applied to the analysis of Federal R&D investments. The model, which is well known to economists/practitioners of social benefit-cost analyses, is expected to serve as a theoretical anchor and unifying framework for the valuation of economic benefits in the EERE retrospective benefit-cost studies addressed by this Guide.

The simplified representation in Figure I-4 of the Griliches/Mansfield model serves to illustrate the valuation approach.

[11] Griliches (1958), E. Mansfield, J. Rapoport, A. Romeo, S. Wagner, and G. Beardsley (1977); Foster Associates, (1978); Nathan Associates (1978), , "Net Rates of Return on Innovations," Report to the National Science Foundation, July 1978.

Suppose that an innovation results in a new product used by firms that reduces costs of the industry using the innovation. The social benefits from the innovation can be measured by the profits of the innovator plus the benefits to consumers of the goods produced by the industry using the cost-reducing innovation. To the extent that the innovation is adopted (or adapted) in other applications, a similar approach could be taken in each application and the total social benefits (less costs) aggregated. Professor Mansfield acknowledged that the calculations are not this simple, but indicated that the basic model conveys the spirit of the analysis.[12]

Figure I-4 Griliches/Mansfield Model of Social Benefits from an Innovation that Reduces the Cost of Producing a Good Sold



Source: Edwin Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology,* 1996.

With reference to Figure I-4, DD' depicts a demand curve for the goods using the cost-reducing innovation. The horizontal supply curve labeled S1 reflects the pre-innovation supply of the goods, and P1 indicates the pre-innovation price paid by consumers. The horizontal supply curve labeled S2 reflects the post-innovation shift downward of the supply curve due to decreases in production costs, and P2 indicates the new price that consumers will pay. The top-hatched area indicates the gain in consumer surplus, due to

[12] Professor Mansfield was engaged by the Advanced Technology Program to extend his model to apply in benefit-cost studies of ATP-funded innovations. This brief description of his model is from a preliminary planning report for that effort. Edwin Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities*, National Institute of Standards and Technology, GCR 99-780, January 1996 (Available on-line at www.atp.nist.gov/eao/gcr99-780/contents.htm).

the innovation. It is the excess of what consumers would have been willing to have paid for the new quantity versus what they actually had to pay, summed over all purchases.

How far downward the supply curve will shift depends, of course, on the effect of the innovation, the pricing policy of the innovator, and the competitive structure of the industry sector. If the industry sector is characterized by little competition, the innovator may be able to hold the product prices relatively unchanged, such that the supply curve shifts little or none. However, if the industry sector using the innovation is competitive, it is expected that the innovator will lower the price for its new product as others enter with competing products.

The social benefits from the innovation can be measured by the sum of the two cross-hatched areas in Figure I-4. The top cross-hatched area is the consumer surplus due to the lower price (P2 rather than Pl) resulting from the use of the innovation. In addition, there is a resource saving, and a corresponding increase in output elsewhere in the economy, due to the fact that the resource costs of producing the good using the innovation are less than P2 Q2. Instead, they are P2 Q2 minus the profits of the innovator from the innovation (r), the latter being merely a transfer from the producers of the good using the innovation to the innovator. Thus, besides the consumer surplus arising from the price reduction, there is a resource saving amounting to the profits of the innovator. For example, suppose the innovator reaps a $100 million profit from its innovation. This means that P2 Q2 is an over-estimate of the value of the resources used by the industry, in the amount of $100 million; the amount the industry pays the innovator in profits. Recall that this payment to the innovator is not in exchange for resources; rather, it is a transfer of profit to the innovator.

Two adjustments are needed in the estimate corresponding to the lower shaded area in Figure I-4. First, if the innovation replaces another product, the resource saving cited above does not equal the profits of the innovator. Instead it equals these profits less those that would have been made (by the innovator and/or other firms) if the innovation had not occurred and the displaced product had been used instead. Second, if other firms imitate the innovator and begin selling the innovation to the industry that uses it, their profits from the sale of the innovation must be added to those of the innovator to get a full measure of the extent of the resource saving due to the innovation.

Using this model, an estimate can be made of the social benefit in each period from the investment in a given innovation. For each innovation, the top shaded area in Figure I-4 equals,

$$(P1 - P2)\ Q2\ (1 - 1/2\ Kn) \qquad (1)$$

where K = (P1 - P2)/P2, and n is the price elasticity of demand (in absolute value) of the product of the industry using the innovation.

To estimate P1 - P2, Mansfield’s approach was to obtain as much information as possible on the size of the unit cost reduction due to the innovation. To obtain a reasonably reliable estimate of (P1 - P2), Mansfield conducted interviews with executives of the innovating firm, executives of a sample of firms using the innovation, and reviewed reports and studies made by these firms for internal purposes. And with the estimate of (P1 - P2), it was then possible to compute K. Q2 was generally available from published records. Rough estimates of n were obtained from published studies and from the firms. Since K was generally very small, the results were generally not very sensitive to errors in n.

Indeed, Mansfield concluded that the expression in equation (1) could be approximated well in most cases by (P1 - P2) Q2, which is the total savings to consumers due to the lower price if they buy Q2 units of the product of the industry using the innovation. This latter point has been helpful in the practical application of Mansfield's model.

To use the Griliches/Mansfield model for estimating net benefits from a public-sector innovation, the approach is to estimate social benefits as the stream of consumer and producer surplus resulting from an innovation. The counterfactual case is assumed to be the technology and associated demand and supply situation that existed just prior to the innovation and that would have existed without the innovation. The social cost is the combined public and private R&D and related costs over time incurred for the purpose of innovation. Public benefit is the part of social benefits attributed to the public investment, plus any reductions in realized total social costs compared with counterfactual total social costs. Public investment cost is the cost of the public program.

Note that the Mansfield approach includes market spillover effects which occur as others in the same industry as the innovator, within competitive markets, use the innovator's knowledge to imitate the innovation and drive down prices to consumers. Not included in the simplistic depiction of Figure I-4 are effects that occur as firms outside the innovator's industry draw from the same knowledge base to produce other goods and services in other industries. Also not included are non-economic effects, such as environmental, energy security effects, and the more general effects of an enhanced knowledge base on the capacity of organizations to innovate in other areas. These later effects are addressed explicitly by the EERE approach.

I.3 Special Features of the EERE Benefit-Cost Approach

This section briefly describes the special features of the EERE benefit-cost approach. They are:

- Use of a cluster approach
- Extension of the benefits evaluation to account systematically for multiple categories of benefits – energy, labor, and other resource effects, environment, energy security, and knowledge diffusion
- Improved characterization of the next-best alternative
- Detailed analysis of attribution of benefits

- Focus only on retrospective, empirically-based benefits and costs
- Exclusion of treatment of employment and regional effects
- Qualitative/quantitative treatment of international effects only if important to the assessment of public benefits
- Use of sensitivity analysis

Each of these features is briefly described below.

Cluster Approach

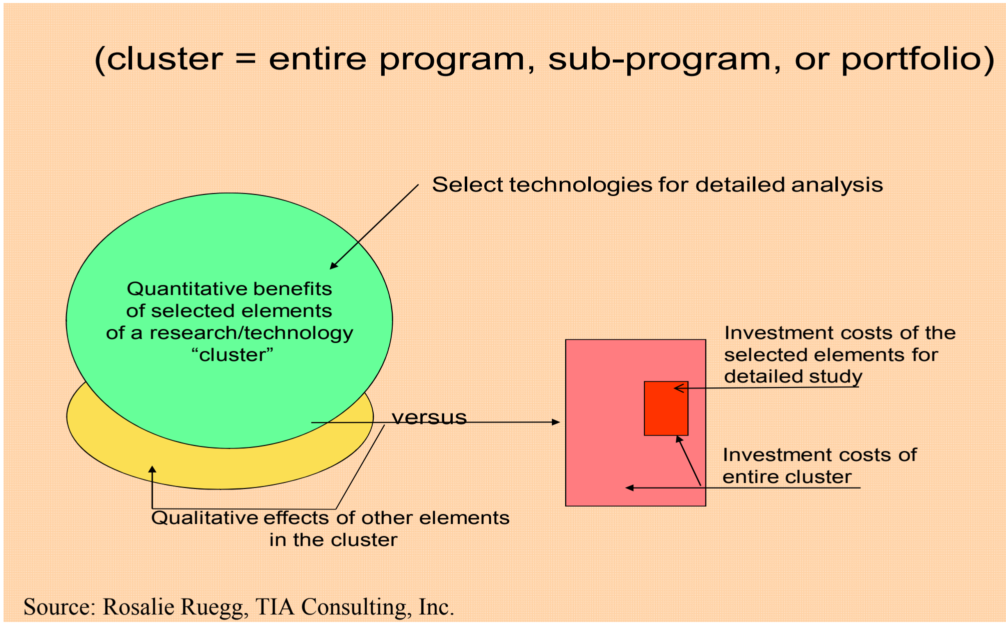
EERE's approach extends the analysis to "clusters" or portfolios of projects, with a cluster consisting of an entire program or subprogram or other grouping of similar technologies or related projects. Selected individual technologies within a cluster are evaluated in detail; remaining technologies within the cluster are treated qualitatively. Benefits of the selected technologies may be compared against their own costs, but, more importantly, they are compared against the investment cost of the entire cluster, as illustrated in Figure I-5. The resulting economic performance measures of benefits against cluster costs provide a minimum rate of return on EERE's investment in the program cluster – a lower bound estimate.[13]

The EERE cluster approach tends to be cost-effective because it enables the evaluation to be focused on a relatively few projects in a larger R&D portfolio (project or subprogram portfolio), while enabling broader conclusions to be drawn about an entire program or a subprogram. Furthermore, the approach works well for high-risk R&D programs where a few projects tend to be the big winners, but investment in an array of projects is necessary to find the few that will turn out to be highly successful.

From the standpoint of a program manager, cluster analysis offers the possibility of presenting a strong evaluative position. The strong position is that of being able to demonstrate that benefits from only a few elements in a larger cluster more than offset all program cluster investment costs, while additional elements in the cluster also hold promise of additional benefits or, at a minimum, offer little threat of offsetting effects.

[13] As noted earlier, the use of benefit-cost analysis applied to technology clusters was pioneered by the U.S. Advanced Technology Program (ATP) in the early 2000s.

Figure I-5. Illustration of Benefits versus Costs in EERE Benefit-Cluster Approach



Multiple Categories of Benefits

The EERE approach extends the comprehensiveness of the benefit-cost analysis by credibly accounting for multiple categories of benefits. EERE assessment of benefits includes the following four categories, pushing coverage substantially beyond traditional benefit-cost studies:

- **Energy and Economic Benefits** — taking into account all affected resources in the economy, including energy, labor, and other resource effects estimated in dollars, and following the general approach of the Griliches/Mansfield model. Economic benefits are increases in the value of goods and services in the economy. Technological advancement is one way to increase economic benefits. This occurs by improving the performance of existing goods and services and/or reducing their costs, and by developing novel goods and services that provide desired new capabilities and experiences with economic value.

  Energy effects are part of economic benefits, but they are also treated separately because energy is the focus of the EERE programs. Energy effects are assessed in terms of energy saved, or MW capacity generated by renewable in lieu of fossil-based generation.

- **Environmental Benefits** — greenhouse gases, and public health effects from reductions in air emissions including mortality and morbidity effects and dollars of health cost avoidance calculated using EPA's COBRA Model; plus any notable other environmental effects (e.g., water discharges, land resource use, and solid waste generation).

- **Energy Security Benefits** — expressed as imported barrels of oil equivalent units avoided for displaced fossil fuels and also billions of gallons of gasoline equivalent (GGE) and millions of cubic feet of natural gas;[14] and includes qualitative identification of notable effects on the security of energy infrastructure.

- **Knowledge Benefits** — creation and dissemination effects of knowledge outputs of the cluster as indicated by chiefly by patent and publication counts and citation analysis, together with treatment of other knowledge creation and dissemination effects as feasible.

Improved Characterization of the Next-Best Alternative

The benefits of a new or improved technology are assessed in comparison with the next best alternative, i.e., the best choice that could be made in lieu of choosing the new technology. The next-best alternative is also often called the "defender technology." The performance of the defender technology provides a baseline against which to take the performance differences afforded by the new or improved technology. If the defender technology would likely have been improved over time if not displaced by the new or improved technology, estimation of the baseline may require dynamic modeling. Incorrect identification of the defender technology can result in substantial errors in benefit estimation. To support sound selection of the defender technology, Part II of the Guide provides examples of conditions that will influence its determination.

Detailed Attribution of Benefits

Assigning attribution for assessed benefits is a particularly key step in the EERE approach. The observation of positive effects does not necessarily mean that the EERE R&D cluster investment was responsible for generating the benefits. Other potentially causal factors must be taken into account and eliminated as rival explanations for benefits generation.

In contrast to the EERE attention to attribution, benefit-cost analyses often simply assume that all observed benefits are attributed to the subject investment. Alternatively, they use a simple rule-of-thumb. Rather than rely on a simple rule-of-thumb approach to attribution, the evaluation approach presented by this Guide promotes a detailed, case-by-case approach to assessing attribution.

To focus attention on the detailed attribution of benefits at the various stages of technology development, the matrix in Figure I-6 is provided to guide the evaluator in the comprehensive assessment of attribution. The tabular framework helps map attribution to

[14] Monetary value was not applied to barrels of oil equivalent units because the methodology is considered to require further development.

Figure I-6. Detailed Assessment of Benefits Attribution

A Matrix for Assessing Attribution by Technology Stage

Categories of Information Needed for Additionality Assessment	Technology Timeline (Stage of Research, Development, and Commercialization)→					
	Preliminary & detailed investigation	Develop components	Develop system	Validate/ demonstrate	Commer-cialize	Market Adoption
History of the technology						
What DOE Did						
What Others Did (Rival Explanations—Private Sector and Other Nations)						
What Others Did (Rival Explanations –US & State Government)						
The DOE Effect						
Description of DOE Influence And its strength						
Basis of evidence of influence						

the technology timeline to show when each identified effect is estimated to have occurred, to identify and eliminate rival explanations, and to indicate the range of attribution to the R&D program.

Supporting evidence of attribution is provided by the publication and patent analysis that is done to assess knowledge benefits. The knowledge benefits assessment demonstrates quantitatively and qualitatively the linkages between the publicly funded R&D and downstream commercial activities.

Only Retrospective, Empirically Based Benefits and Costs are Included

The measures for each category of benefits are to be derived fully from retrospective analysis, rather than life-cycle or prospective analysis. Only the benefits achieved, and costs incurred, are taken into account; no projections are included. The impact results quantified are thus also <u>fully retrospective.</u>

Quantification of monetary value of some externalities (e.g., CO_2, energy security) are excluded because current approaches to estimating for damage costs do not at this time support an acceptable level of confidence.

Exclusion of Employment Effects and Regional and International Effects

Employment Effects

Beyond the inclusion of labor costs as a resource that may figure in economic benefit-cost analysis, the Guide includes no specific requirement for the treatment of employment effects, such as estimate of numbers of jobs created or retained, or salary effects.

There are several reasons for this decision to omit the treatment of employment effects. One reason for the omission is the fact that many of the past investments treated in retrospective evaluations were done under conditions approaching full employment—they were not planned or implemented with a specific goal of achieving employment. Under conditions of national full employment, the assumption was that jobs added by one investment would be offset by transfers from jobs elsewhere, rather than resulting in net job gains.

More recently, with unemployment a pressing issue and energy projects part of the Federal economic stimulus package, employment effects of energy projects have gained attention. With employment goals for energy investments, the explicit treatment of employment effects in terms of number of jobs created or retained and salary effects may be added to future retrospective benefit-cost studies of energy projects. If this happens, it will be noted in the release of an Addendum to this Guide.

Regional Effects

Aside from specific regional development efforts taken at the Federal level, regional shifts in economic activity are generally not separately included in Federal evaluations. Rather, Federal evaluations typically are focused on national economic effects, and regional shifts are assumed to have a neutral national effect. Thus, regional effects are not called out for separate treatment in the EERE benefit-cost studies.

International Effects

There is little precedence for treating international effects in Federal benefit-cost studies. Also, there is the more immediate concern that requiring their treatment would exceed the resource and time constraints of project funding levels.

In the case of certain technologies, however, a treatment of international effects will be needed to understand national impacts. For example, it is difficult to understand returns to the U.S. public investment in NiMH batteries without having at least some understanding of the development and interrelationships of R&D, innovation, battery commercialization, and markets for battery applications in different parts of the world.

Thus, evaluators of EERE benefit-cost studies are encouraged to provide an overview of international effects, as well as a more detailed assessment of international developments when they are critical to estimating and understanding national benefits in a given technology area.

Use of Sensitivity Analysis

Even for a retrospective, empirically based evaluation, there will be uncertainties about assumptions, data, and, therefore, results. The EERE approach emphasizes the identification of areas of uncertainty and the use of sensitivity analysis to reveal how changes in uncertain values of critical inputs will affect overall estimates of benefits. [15] Examples of input variables that might be subjected to sensitivity analysis are the quantity of energy saved or the degree of attribution of benefits to the program cluster.

[15] Sensitivity analysis is an approach widely used in economic impact studies to acknowledge that there are uncertainties, and to test the effect of changing one or more key input values for which there is uncertainty. When the probabilities that input values differ from "best-guess" estimates are known, risk assessment can be used--instead of sensitivity analysis--to assess the risk exposure inherent in an investment decision. Risk assessment techniques include expected value analysis, decision analysis, simulation analysis, and other techniques described by Ruegg (1996). Risk assessment techniques may also be used in the EERE approach, but are not required. For more on sensitivity analysis, see Saltelli, Chan, and Scott (2000) and Marshall (1996).

Part II. Step-by-Step Guide

Overview of a Step-by-Step Approach

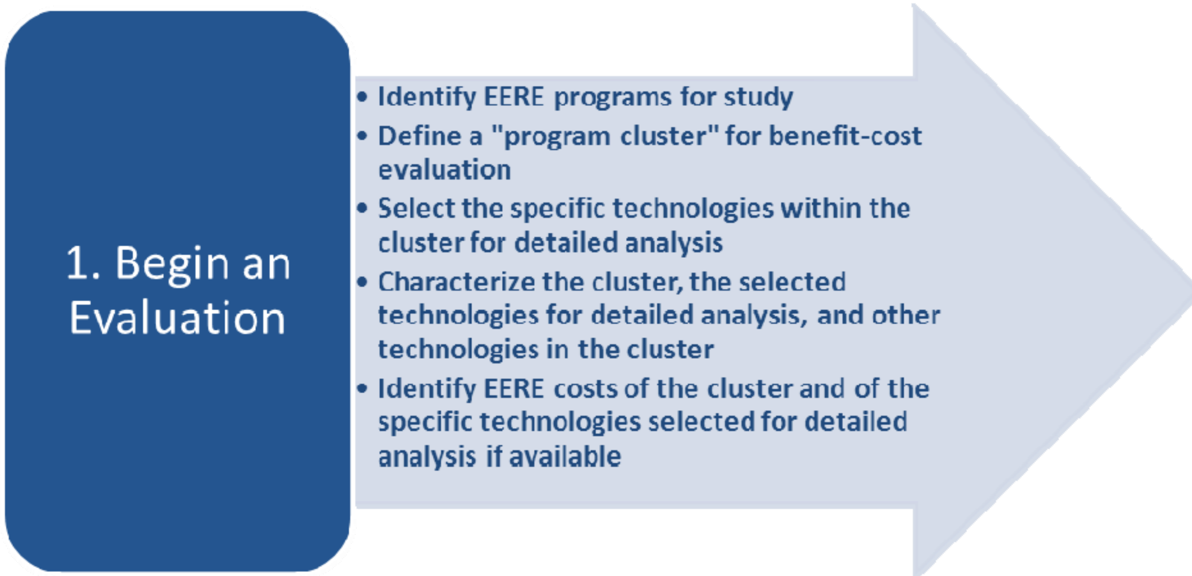
An overview of the step-by-step flow diagram of the EERE approach to retrospective benefit-cost cluster analysis is given in Figure II-1.

It should be emphasized that depicting the evaluation approach as a series of sequential steps does not mean that the process is either linear or formulaic. Conducting a successful study requires an evaluator experienced in both the art and science of benefit-cost analysis, able to capture complex and multiple direct and indirect effects of a public investment using creativity and a variety of techniques within the organization of a step-wise approach, and aware of the dynamic nature of the process.

Part II of the Guide follows the logic of the diagram in Figure II-1. Key process steps are indicated in the text by the symbol "►". Examples from the first-round of 2010 studies are selectively presented to illustrate key steps and are indicated in the text by the symbol ◙.

Figure II-1. Major Steps in the Evaluation Process

1. Begin an Evaluation



► Identify EERE programs for study

A starting point for benefit-cost evaluation is determining which EERE program to evaluate. This likely may be done internally by the EERE staff with the subsequent issue of an EERE Request for Proposal (RFP), or it may be done jointly by a contracted evaluator and EERE staff. The identification of a program cluster follows this initial step.

In general, an EERE program that could benefit from participating in an impact evaluation study conducted according to this Guide would be --

- One for which return on investment is currently not known; or
- One that was previously evaluated in the 2001 NRC study but,
    - had shown no significant realized economic return on R&D investment, in part because accrued market value had not been established for its commercialized technologies during the period of the NRC study, or
    - had successfully commercialized technologies that were excluded from a previous benefit-cost study, or
- One previously evaluated but requires an update (e.g., 2 to 5 years later), or
- One that had performed benefit-cost calculations using an alternative approach not consistent with the EERE approach presented in this Guide.

► Define a "program cluster" for benefit-cost evaluation

Evaluators are expected to work collaboratively with Program staff to define a program cluster for benefit-cost analysis. In the event that they are responding to an EERE Request for Proposal (RFP), the EERE Program staff will typically have identified the program cluster for study in advance.

The program cluster identified for study may be defined as:

1) An entire program's portfolio of related projects/activities,
2) A comprehensive collection of related projects/activities with a shared objective that forms a subprogram or category within a larger program, or
3) A set of related projects/activities that cut across several programs but share a common feature that makes it reasonable and desirable to group them.

Thus, the program cluster may comprise an entire EERE Program, a Sub-program, or some other grouping or portfolio of projects or technologies that share common attributes**.**

The step of "defining a program cluster" is to be implemented in close coordination with "selecting specific technologies within the cluster" and "characterizing the cluster" – described below. This is because often preliminary explorations will need to be done to assess the feasibility of a given program cluster for study. Preliminary explorations would entail taking note of the market uptake of candidate technologies, preliminarily considering their likely impacts, and assessing data availability and other feasibility conditions for studying the program cluster.

In a 2010 study for DOE's Advanced Combustion Engine R&D (ACE R&D) the program cluster was taken as the ACE research effort. This included R&D for Laser Diagnostics and Optical Engine Technologies, Combustion Modeling, Combustion and Emission Control, and Solid State Energy Conversion. The ACE R&D Sub-Program is one of eight sub-programs within a larger DOE Vehicle Technologies Program. In the ACE R&D benefits-cost study, the program cluster was the entire R&D portfolio comprising R&D in the ACE subprogram.

► Select specific technologies within the program cluster for detailed analysis

After the program cluster has been identified, the next step is to select a few technologies within the cluster for detailed benefit-cost analyses (again in collaboration with EERE Program staff or as specified by the RFP). The technologies selected for detailed study could be, for example:

- A whole system (e.g., an advanced wind turbine or a geothermal plant); or
- A component of a larger system (e.g., blades for a wind turbine, or high temperature cement for a geothermal well application); or
- Infrastructure technology that enables a commercial advancement (e.g., new modeling capability, test results, or new designs); or
- A new or improved process (e.g., turbulence modeling for wind turbine inflow, or improved, faster deposition methods for solar PV thin films).

Because benefits of the few technologies in a cluster selected for detailed study will be compared against total EERE cluster costs, it makes sense—and, in fact, it is a feature of the approach—that those selected should be among the most successful in having achieved technical and commercial results prior to the study cut-off year[16] for the analysis. Further, it should be feasible to assess the benefits of those technologies selected.

Near term technologies not yet in commercial production are excluded from selection for detailed analysis. This exclusion extends to technologies that are in final development and demonstration stages at the time of selection, but which are not expected to have entered the market under currently projected economic, regulatory, and tax conditions until after the study cut-off year. This criterion is consistent with retrospective analysis which uses empirical data rather than projections. Also excluded from selection are technologies whose benefits cannot be feasibly measured. The example in Table II-1 lists clusters and technologies selected for detailed analysis within each cluster, from recently completed 2010 studies.

> In the previous example, a subset of technology/ research areas from within the ACE R&D cluster was selected for examination in the benefit-cost assessment. The specific technologies within the cluster selected for detailed analysis were
>
> - Laser diagnostic and optical engine technologies focused on heavy-duty diesel engines
> - Combustion modeling –in particular KIVA modeling that simulates the fluid dynamics of combustion processes in internal combustion engines
>
> Combustion and Emission Control and Solid State Energy Conversion were not included in the quantitative benefits analysis for the ACE R&D benefit-cost study, although the total cluster cost was accounted for in the analysis.

► Characterize the program cluster, the selected technologies for detailed analysis, and other technologies in the program cluster

For context, provide an overview of the program cluster to be studied, and of the technologies within the cluster selected for detailed analysis. Describe the objectives to be achieved by the program cluster, activities undertaken in support of these objectives, and how the technologies selected for detailed analysis have affected resource use. Explain why the program cluster and the technologies for detailed analysis were selected.

While the quantitative analysis centers on those several technologies selected for detailed analysis, it is important also to provide at a minimum a qualitative review of other elements in the program cluster. The aim is to give a sense of the likely overall impact on program cluster net benefits of these other elements within the cluster. Is there reason to believe that these other elements will not offset any positive effects of the selected technologies? Is there reason to believe they will provide additional benefits?

[16] For each of the four benefit-cost studies completed in 2010, the study cut-off year was end of 2008. The cut-off year will vary, depending on the year a study is initiated and availability of data for the analysis.

Table II-1. Program Clusters and Selected Technologies for Detailed Analysis within Each Cluster, 2010 EERE Benefit-Cost Studies

Four Program Clusters (2010 Studies)	Technologies within Each Cluster Selected for Detailed Analysis (2010 Studies)
Geothermal Technologies Program	• Polycrystalline diamond compact (PDC) drill bits • Binary cycle power plant technology • TOUGH series of reservoir models • High-temperature geothermal well cements
Wind Energy Program	• Wind turbulence models • The unsteady aerodynamic experiment to acquire accurate aerodynamic and structural measurements • Turbine blade material characterization and analytical modeling work • Wind turbine component demonstration programs
Photovoltaic (PV) Energy Subprogram of the Solar Energy Technology Program	• Flat-Plate Solar Array project • PV Manufacturing Technology Project • Thin-Film PV Partnerships
Advanced Combustion Engine R&D Subprogram of the Vehicle Technologies Program	• Laser diagnostic and optical engine technologies focused on heavy-duty diesel engines • Combustion modeling --in particular KIVA modeling that simulates the fluid dynamics of combustion processes in internal combustion engines

► Identify EERE costs of the program cluster and, if possible, of the specific technologies selected for detailed analysis

Cluster costs are the cost of the program or subprogram or other portfolio chosen for study. Thus, costs of all projects within the cluster are to be included; nothing within the cluster scope is to be left out of cluster costs.

Total program and subprogram costs should be available for past years from the program. However, costs broken out for parts of subprograms or for individual technologies within a cluster may be less readily available. Because total cluster costs are essential to computation of the desired economic performance metrics, obtaining them is imperative. As soon as the cluster is defined, program staff should take steps to provide cost data for the relevant cluster to the evaluators, and the evaluators should request the cost data from the program.

This is a critical step in the entire process. It requires consistency of program budgeting practices over time or the regrouping of subprograms by those knowledgeable of past practices and adjustments to budget categories to provide the required cluster cost data.

It is program's responsibility to provide the necessary cluster data to the evaluators. It is evaluator's responsibility to bring this requirement to the attention of program staff.

Cluster costs should be presented year-by-year over the entire period of the program's investment. Costs can be expressed in actual dollars at the outset, but are to be converted to yearly inflation-adjusted constant dollars for the designated year.[17]

At a minimum, evaluators are asked to assemble the program investment costs data for the entire program and obtain data for the program cluster (or subprogram), as well. For example, the entire DOE Wind Energy Program investment ($1.7 billion, $2008 inflation adjusted), as well as the R&D costs of the selected infrastructure technologies ($1.2 billion) was assembled for the Wind benefit-cost study. For the Wind Energy Program example, the time series of costs of the program cluster versus the total program cost over the historical period 1976 to 2008 are given in Table II-2.

Economic performance measures are calculated and reported based on both the entire program and the cluster costs. If the costs of the individual technologies selected for study are separately identified, the evaluators are instructed to also calculate net economic benefits based on the investment relevant to the selected technologies examined. At a minimum, they are asked to report calculated results for the total cluster investment.

In a 2010 Wind Energy R&D Benefit-Cost study, the cluster and selected technologies were characterized as infrastructure technologies –

- Wind turbulence models
- The unsteady aerodynamic experiment to acquire accurate aerodynamic and structural measurements
- Turbine blade material characterization and analytical modeling work
- Wind turbine component demonstration programs.

In the benefit-cost study, the selected group of infrastructure technologies were treated as a group of infrastructure technologies, rather than separately.

Public investment in these infrastructure technologies represented only a portion of the total public investment of the Wind Energy Program – i.e., 70% of its total historical budget.

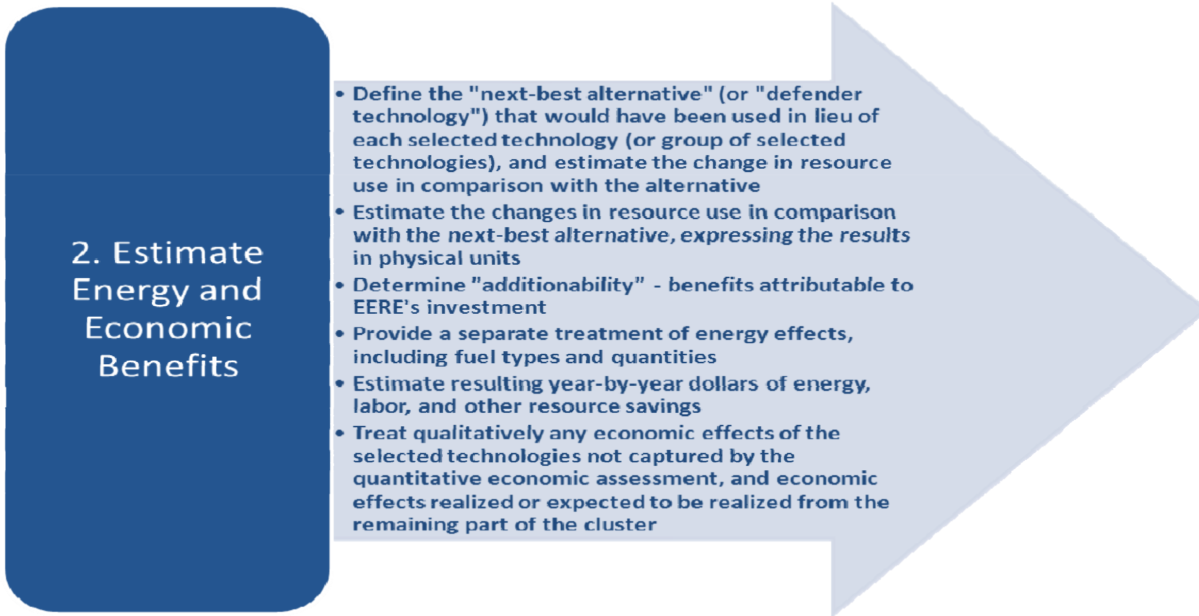
[17] See addendum pertaining to key dates and other updated information applicable to current studies.

Table II-2. Investment Costs in the Wind Energy Program (the Benefit-Cost Study Cluster) and Investment Costs for Selected Technologies within the Cluster

Year	Investments in Selected Infrastructure Technologies Nominal (Thousand Dollars)	Total Wind Energy Program Investments Nominal (Thousand Dollars)	Inflation Adjusted Investments in Selected Technologies 2008 Dollars (Thousand Dollars)	Inflation Adjusted Total Wind Energy Program Investments 2008 Dollars (Thousand Dollars)
	(1)	(2)	(3)	(4)
1976		14,403		44,027
1977		20,500		58,910
1978	34,470	35,300	92,560	94,788
1979	58,155	59,555	144,166	147,636
1980	56,254	60,555	127,801	137,572
1981	76,087	77,500	158,050	160,985
1982	37,700	38,400	73,807	75,178
1983	31,290	31,390	58,928	59,116
1984	26,367	26,367	47,860	47,860
1985	28,155	28,355	49,603	49,955
1986	12,536	24,786	21,608	42,723
1987	11,930	16,606	19,983	27,816
1988	8,064	8,464	13,059	13,707
1989	8,260	8,760	12,890	13,670
1990	8,498	8,687	12,768	13,052
1991	10,836	11,034	15,724	16,011
1992	21,082	21,282	29,883	30,167
1993	5,500	23,841	7,628	33,063
1994	9,334	29,151	12,678	39,593
1995	11,784	34,309	15,679	45,648
1996	16,830	31,420	21,974	41,023
1997	20,540	28,646	26,353	36,752
1998	17,301	32,128	21,949	40,759
1999	20,861	34,076	26,082	42,604
2000	17,219	31,734	21,072	38,835
2001	19,902	39,132	23,817	46,830
2002	21,731	38,211	25,592	44,999
2003	26,282	41,640	30,299	48,005
2004	26,188	39,803	29,358	44,621
2005	24,053	40,631	26,093	44,078
2006	17,276	38,333	18,150	40,273
2007	29,839	48,659	30,476	49,698
2008	22,643	49,034	22,643	49,034
Totals Investments	**736,967**	**1,072,692**	**1,238,531**	**1,718,989**

Source 1: Pelsoci (2010).

2. *Estimate Energy and Economic Benefits*



► Define the "next-best alternative" (or "defender technology") that would have been used in lieu of each selected technology (or group of selected technologies), and estimate the change in resource use in comparison with the alternative

The merits of the selected new technology are judged against the next best alternative, i.e., the best choice that could have been made in lieu of choosing the new technology. For a retrospective benefit-cost analysis, the next best alternative is defined by looking back to the time the investment decision was made for the new technology. That is, the next best technology at the time of the investment decision is not necessarily today's next best alternative. It is the choice **not** taken, and therefore it represents a counterfactual comparison.

In defining the next best, or defender technology, it is necessary to determine whether to use static or dynamic modeling. Based on what is known about the defender technology, it should be possible to determine whether it is more appropriate to model it as remaining constant or changing in performance over the period of comparison.

There is an element of judgment in the selection of the next best alternative—even for retrospective studies—but there are also determining factors to consider. One of these factors is whether the choice was constrained or unconstrained. For example, if use of a renewable energy system were required (say by a State requirement), investment in a renewable system would be compared against other renewable energy systems. Another factor is whether the technology was new to the world or an improvement over an existing system. If it was new to the world, it might be compared against the best alternative conventional technology. If the technology was an improvement over an existing system, it would likely be compared against the then best existing earlier system model. Table II-3 gives examples of the next-best alternatives identified for the four 2010 EERE Benefit-Cost Studies. The first column lists the study and technologies evaluated in detail, and the second column describes the next-best alternative.

Table II-3. Examples of Next-Best Alternatives Identified in 2010 Benefit-Cost Studies

Study (1)	Next-Best Alternative (2)
Advanced Combustion Engine (ACE) R&D Subprogram--laser and optical diagnostics	The state-of-the-art in diesel engine design and related brake thermal efficiency (BTE) that existed prior to 1995.
Geothermal R&D Program -- with 4 distinct technology cases	
1. Polycrystalline Diamond Compact (PDC) Drill Bits	Existing roller-bit drill technology.
2. Binary cycle power plant	For reservoir temperatures in the range of 150 to 190° C, flash cycle technology; and for temperatures in the range below 150° C, a coal power plant.
3. TOUGH series & related reservoir models	"Lumped parameter" models used before capabilities for detailed computer simulation of reservoirs were developed.
4. High-temperature geothermal well cements	Existing Portland cements.
Solar Photovoltaics R&D Subprogram--cSi modules and thin-film modules	Existing inferior crystalline silicon PV modules that would have been continued during the delayed introduction of the improved PV modules technology.
Wind Energy R&D Program--group of infrastructure technologies	Fewer, smaller, less reliable, less cost-competitive wind turbines with lower energy capture that would have been used during the delayed introduction of turbines based on the improved infrastructure technologies

It is a requirement that the benefit-cost study describe in the final report how the study has defined the next best alternative for each technology or group of technologies selected for detailed analysis, and what was the rationale.

► Estimate the changes in resource use in comparison with the next-best alternative, expressing the results in physical units

Perform year-by-year comparisons of the selected technology or group of technologies against the appropriate next best alternative to derive the differences in each type of affected resource stated in physical units. For example, what are the differences in quantities of energy consumption by type? What are the effects on labor requirements? What are the differences in purchase, installation, and maintenance costs? What are the differences in life expectancies?

These effects may differ among the selected technologies or groups of technologies and, if so, will require separate, individual comparisons with each next-best alternative.

It is at this stage that incremental energy savings and/or MW capacity is derived from differences in the performance characteristics of the selected technology and its next-best alternative. There are a variety of ways resource savings and associated energy/ fuel changes can be calculated, and the specific approach depends on the selected technology and available data. The calculation approach and results should be well documented in the study report.

The following are two examples for illustrative purposes --

(1) Wind Energy Benefit-Cost Study Example, Pelsoci (2010), where billions of kWh of electricity otherwise supplied by fossil fuel (calculated by type of fuel) were displaced by wind energy. (See Example A below)

(2) Advanced Combustion Engine (ACE) R&D Benefit-Cost Study Example, Link (2011), where billions of gallons of diesel fuel were saved. (See Example B and Figure II-2)

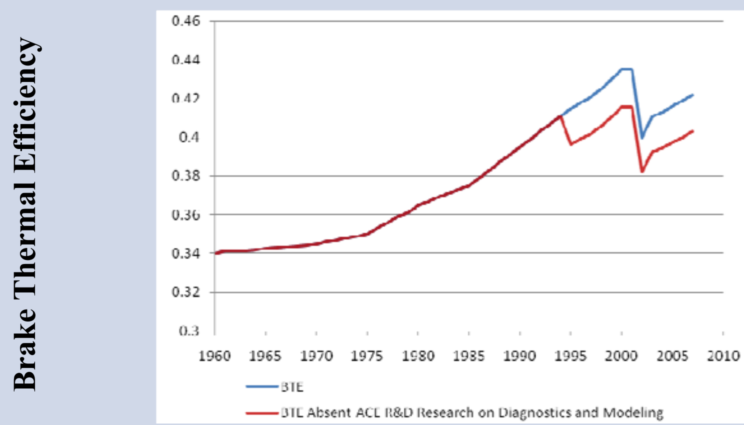
Example A: In the wind energy study, it was determined there was a six year acceleration effect, as determined from interviews with experts. Six was the mean value of the distribution of responses. This acceleration led to wind energy supplying 139.8 billion kWh that displaced electricity otherwise supplied by a fossil-fuel generation mix (where the mix is determined from the weighed fuel use of energy generation from fossil fuel mix of the States with the largest share of wind energy power):

- 61.5 billion kWh (i.e., 44% of total from wind) supplied by coal-fired generation
- 76.9 billion kWh (i.e., 55% of total from wind) supplied by natural gas-fired generation
- 1.4 billion kWh (i.e., 1% of total from wind) supplied by petroleum-fired generation.

This information provided the energy benefits estimate (e.g., power generation from wind) and also produced the inputs to the subsequent environmental emissions analysis for that benefit-cost study.

Example B: In the ACE R&D study, a statistical approach was adopted for the calculation of the fuel savings associated with miles per gallon (MPG) fuel economy improvements, where MPG improvements were linked to a 4.5% DOE-supported R&D improvement in Brake Thermal Efficiency (BTE) – shown in Figure II-2 (expert-derived counterfactual BTE). The change in MPG was statistically estimates ($\partial MPG / \partial BTE = 0.153$) and the reduction in MPG absent the ACE R&D research was calculated. The calculated reduction in MPG was translated to reduced fuel consumption of 17.6 billion gallons of diesel fuel saved over the period 1995 to 2007.

Figure II-2. Trend in BTE over Time with Counterfactual



Source: Link (2010).

There may be multiple potential approaches to estimating energy benefits in benefit-cost studies. It is important to fully document the estimation approach used and the rationale.

► Determine "additionality" — benefits attributable to EERE's investment

The focus of the study is on estimating the return on EERE's investment, i.e., the "return on public investment." This entails delineating the part of the benefits from using the selected technologies in the cluster — in lieu of the next best alternative — that are attributable to the cluster investment. This step, often referred to by the program evaluation community as "assessing additionality," takes into account the possibility that to some extent development of the selected technologies may have occurred without the cluster investment.

This step to assess additionality—also counterfactual in nature—is an essential step in evaluating returns to the designated EERE cluster investment. It considers what likely would have happened without the EERE cluster investment. Only if the selected technologies would not have been developed and applied at all without the EERE cluster investment would the entire impact of the technology as computed against the next best alternative be appropriately attributed to the EERE cluster investment. In contrast, if it appears likely that the selected technology development and application would have happened in the same way, in the same timeframe without EERE as with it, then none of the benefits of the subject technologies can legitimately be attributed to the EERE cluster. These two cases represent the extremes, however, and the answer is more often found between these end points.

The assessments of additionality and next-best alternative are sometimes combined. However, the EERE approach calls for explicit treatment of each. Keep in mind that the purpose of the next-best-alternative component of the analysis is to determine the benefits of having the selected technologies versus not having them. In contrast, the additionality component of the analysis is to determine what share of the benefits of having the selected technologies is attributable to the R&D Program.

Table II-4 lists ways that Federal technology investments can cause change to occur. Ask what would have been different without the EERE cluster investment. Is it logical to expect that it gave rise to any of the effects listed in Table II-4? Are there other types of effects, not listed, that may have occurred? Identify and describe the expected additionality effects of the selected technology or group of technologies.

Table II-4. Ways Additionality Can Occur

Types of Effects	**Specific Examples of types of additionality**
Acceleration of technology development & commercialization	• Expanding R&D funding to achieve technical goals faster • Developing supporting research models, data, and designs that speed R&D • Lowering technical risk and removing other barriers to progress • Stimulating market awareness and receptivity
Improvement of technology performance characteristics	• Broadening the scope of R&D effort with larger goals • Increasing scale of R&D effort to take on more difficult and rewarding technical challenges
Reduction in the cost of a technology or the costs associated with its use	• Fostering of collaborative R&D to avoid investment redundancy • Provision of specialized facilities and services needed by an industry to make technical advances
Increase in the size of the market and amount of use of the technology	• Reduce barriers to market adoption, e.g., through demonstrations, information, training, and standards and certification activities • Increase access of U.S. firms to global markets

After identifying how the EERE's investment appears to have influenced change, estimate the extent of the additionality. Document and discuss the evidence that the identified additionality effects have occurred, using the tabular framework provided in Figure I-6 (See Part I). Designed to assist in organizing and reporting the analysis, the use of this framework will help to map attribution to the technology timeline to show when each identified effect is estimated to have occurred, to identify and eliminate rival explanations, and to indicate the range of attribution to the R&D program in terms of a percentage share of benefits generated by use of the selected technology or group of technologies.

The objective of the analysis of additionality is to assess and describe the degree of influence of the EERE in causing the estimated benefits of the selected technologies in comparison with their next best alternative, and to express the degree of influence in terms of a percentage share or preferably as a range of percentage shares (or, if appropriate, in terms of an acceleration effect, which may be expressed as a range of years). The following are suggested terms and associated percentage shares for representing different levels of influence:

- Overwhelming Influence (80-100%)
- Dominant (60-80%)
- Very Important (40-60%)
- Influential (20-40%)
- None to Minimal (0-20%)

Table II-5 gives an example for the Geothermal Program's PDC drill bit technology attribution analysis as summarized in the attribution matrix framework. The matrix serves as a framework and summary of more detailed attribution analysis findings documented in each study report.

The following conditions are expected to be met in attributing effects to the EERE R&D Program in the assessment of additionality:

- The postulated effect must make sense in terms of the R&D Program's logical theory (or logic model[18]) that relates program mission, strategy, activities, and outputs to longer term outcomes.

- If the Program has made a difference, there should be a corresponding time-order change whereby the Program's actions were taken prior to the observed changes and in the direction predicted with a sufficient lead-time to allow the changes to occur. This time order change should be documented, as illustrated in the examples below taken from the recently completed Solar energy benefit-cost study (O'Connor, et al, 2010).

- If there are potential rival explanations of the estimated benefits, these rival explanations need to be controlled for or separated from the effect of the selected technologies, such that it is the effect of the selected technologies that is identified in the additionality assessment and not other causes. Eliminating rival explanations is important because otherwise the benefits claimed for the selected technologies within the cluster could be due to other factors. There are two kinds of rival explanations pertaining to "what others did" (as noted in the attribution matrix framework Figure I-6 in Part I: (a) what other programs, private sector, and other nations did, and (b) what Federal and State Governments did.

[18] See McLaughlin and Jordan (2010).

Table II-5. An example of a completed attribution matrix

Categories of Information Needed for Additionality Assessment	Technology Timeline (Stage of Research, Development, and Commercialization)→					
	Preliminary & Detailed Investigation	Develop Components	Develop System	Validate/Demonstrate	Commercialize	Market Adoption
What DOE support of SNL and others did	▪ Study applicability of PDC drill bits to geothermal fields	▪ Worked on improving performance of drill bits ▪ Financed contracts and R&D efforts with GE	▪ Conducted research on drill mechanics and hydraulics ▪ Developed STRATAPAX and PDCWEAR, which helped place cutters on the drill bit	▪ Sponsored wear and friction tests ▪ Helped establish best practices ▪ Held workshops, sponsored publications and presentations	▪ DOE efforts helped commercialize PDC bits	▪ DOE scientists and engineers contracted with consortium of drill bit manufacturers to continue improving the performance of PDC drill bits
What others did (rival explanations)	▪ GE developed PDC in 1955 and first tested in the field 1973	▪ GE worked on DOE contracts	▪ GE used STRATAPAX to position cutters on drill bits ▪ Industry used PDCWEAR to create anti-whirl drill bits			
Driving/ restraining policies/ government forces (rival explanations)	▪ USGS study showed availability of geothermal fields around United States ▪ Oil crisis, U.S. government studied energy sources alternative to fossil fuels	▪ Oil crisis, U.S. government studied alternative energy sources to fossil fuels (including geothermal)			▪ Demand for oil went up, creating a demand for offshore drilling	▪ PDC bits became enabling technology for horizontal drilling widely used in offshore drilling ▪ Federal and State Tax Credits

Source: Gallaher, et al. (2010)

Table II-5 continued. An example of a completed attribution matrix

Categories of Information Needed for Additionality Assessment	Technology Timeline (Stage of Research, Development, and Commercialization)→					
	Preliminary & Detailed Investigation	**Develop Components**	**Develop System**	**Validate/Demonstrate**	**Commercialize**	**Market Adoption**
Description of DOE influence	▪ **Very Important (50%)** ▪ DOE efforts helped consider applications of costly PDC drill bit technology	▪ **Very Important (50%)** ▪ DOE supported the technology at the time when it seemed too costly and unreliable	▪ **Dominant (70%)** ▪ Developed analytical tools that helped advance the application of the technology ▪ Greatly improves bonding of cutters to drill bit	▪ **Dominant (70%)** ▪ DOE efforts helped show that it is possible to overcome the short-comings of PDC drill bit technology with engineering and research	▪ **Influential (25%)** ▪ DOE's efforts helped deliver PDC bits right before there was an increase in demand for a similar technology, which helped the adoption of PDC bits	▪ **Influential (25%)** ▪ DOE's expertise remained available for the industry to use in their own R&D efforts
Basis of evidence for influence	▪ Interviews with experts ▪ Articles ▪ Studies	▪ Interviews with experts ▪ Articles ▪ Studies	▪ Interviews with experts ▪ Articles ▪ Studies	▪ Interviews with experts ▪ Articles ▪ Studies	▪ Interviews with experts ▪ Articles ▪ Studies	▪ Interviews with experts ▪ Articles ▪ Studies
The DOE effect	▪ Accelerated technology entry	▪ Improved performance	▪ Improved performance ▪ Changed costs	▪ Improved performance		▪ Improved performance

Source: Gallaher, et al. (2010)

The period of analysis for the 2010 Solar benefits-cost study was 1975 to 2008. In that study, some of the time order change reported was:

- Module prices were reduced by a factor of 15, and efficiencies for modules in commercial production increased from about 5% to 10%.
- Reliability improvements sparked by testing at DOE's Flat-Plate Solar Array Project (FSA) allowed companies to offer at least 10-year warranties on modules and subsequently reached 20 years, whereas before FSA, warranties were nonexistent in the PV industry.
- During the period of DOE's Photovoltaic Manufacturing Technology (PVMaT) Project, direct costs of module manufacturing fell from $6.00/Wp (Watts peak) in 1992 to $2.92/Wp in 2005 (2008$).
- During the same period, MW capacity increased 18.5 times to 251 MW).

"What other programs, private sector, and other nations" did could include fuel prices; activities of other entities, including domestic and foreign companies and universities (who did not cost share with DOE), and foreign research laboratories. "What Federal and State governments did" would include requirements influencing investments in subject technologies). Examples of rival explanation factors related to Federal and State government actions:

- o Tax credits (e.g., Production Tax Credit (PTC), Investment Tax Credit (ITC)) and other technology market-supporting policies (such as low-interest loans for renewable technologies) that reduce the effective price of the subject technology.
- o Increases in fuel or other prices, which raise the cost of the next best alternative disproportionately.
- o Renewable Portfolio Standard (RPS)

- Discuss sources and degree of uncertainty regarding the percentage or range of percentages used to describe the degree of influence of the EERE R&D Program.

- Findings regarding additionality may differ within a given cluster study for each selected technology or group of technologies. Thus, the process of assessing additionality is expected to be repeated for each selected technology or technology group within a cluster. Attribution shares may range from 0% to 100%.

As part of the extensive and important effort to determine additionality, a study should employ multiple lines of data and carefully document the basis of evidence of influence. Multiple data could include, for example,

- Public record, patent citations
- Interviews with third parties

- Interviews with partners
- Interview with DOE or DOE lab staff
- R&D cost shares
- Other data source

Furthermore, any efforts to utilize interviews to assist with construction of counterfactual scenarios or determine attribution should seek to obtain necessary data from both DOE partners and third parties who are non-DOE partners. In addition, to the extent possible, a distribution of responses/ judgments from expert interviews should be documented and the mean value chosen as the point estimate further applied in the study for the purpose needed. The distribution of expert responses/ judgments should be documented and described in the study report.

After the additionality analysis has been completed, the attribution effect is applied to the energy and other resource savings found relative to the next-best-alternatives. This may entail taking a percentage share of the pre-attribution savings, or applying the effects of an acceleration to the pre-attribution savings.

►Provide a separate treatment of energy effects, including fuel types and quantities

While all resources are important to estimating economic benefits, there is a special data requirement for energy effects. Differences in the quantity of energy by type associated with technology selection not only figure into economic benefits, but also drive two of the other categories of benefits—environmental and energy security benefits. (Note that the quantity changes in fossil fuel consumption by type are carried forward to Steps 3 and 4.) Thus it is required that all energy effects by type and physical quantity be broken out for separate treatment.

►Estimate resulting year-by-year dollars of energy, labor, and other resource savings for each selected technology or group of technologies

Compile additional data needed to compute year-by-year economic resource savings, such as prices and labor rates.

Estimate year-by-year economic benefits for each selected technology or group of technologies, taking into account the combined effect of the next-best alternative comparison and additionality assessments. Include the effects of all affected resources—including energy, labor, and capital.

If the estimates are in actual (current) dollars, convert yearly current dollars to yearly constant dollars as of the stated year--as indicated by the Guide or Addendum to it--that EERE has selected for which $1.00=1.00. The Guide obtains the needed Gross Domestic

Product (GDP) Implicit Price Deflators from U.S. Department of Commerce's Bureau of Economic Analysis (BEA), at http://www.bea.gov/national/index.htm. These price deflators are routinely updated by BEA, and to prevent variations among the benefit-cost studies, caused merely by using different price deflator series, this Guide prescribes the series of price deflators to be used by all studies conducted within a funding cycle.

Show the calculated year-by-year economic benefits in tabular form for each separately treated technology or group of technologies within a cluster, as well as for each type of economic benefit. Show the sum of constant dollar cash flows as undiscounted economic benefits. An illustration is provided in Table II-6 from the geothermal benefit-cost study (Gallaher, et al, 2010). The table shows the estimation of productivity gains attributed to the DOE Geothermal Program due to its contributions to development of reservoir models.

Repeat the above tabular treatment for each separately treated technology or group of technologies within the cluster. For example, the referenced geothermal study provided separate analyses for four distinct technologies--one from drilling, one from reservoir development, one from well preparation, and one from plant technologies.

Provide an overall summation table that brings together the year-by-year constant dollar economic benefits for each technology or group of technologies within a cluster.

Show the overall undiscounted sum and also the overall PV results for economic effects, based on discount rates of 3% and 7%.

Table II-6. Example from the Geothermal Benefit-Cost Study (2010) of the Estimation of Productivity Benefits from Use of Reservoir Models

(1) Year	(2) Price per MWh of Electricity ($2008)	(3) Geothermal Electricity Generated (MWh)	(4) Electricity Generated by Geothermal After TOUGH Model for Reservoir Simulation Became Widely Used (MWh)	(5) Share of Geothermal Power Generated Due to Reservoir Modeling-- based on 10% share (MWh)	(6) Economic Benefits from Reservoir Modeling (prior to attribution analysis) (thousands of $2008)	(7) Economic Benefits from Reservoir Modeling (prior to deduction of capital costs) Attributed to DOE (thousands of $2008)
1979	na	3,888,968	na	na	0	$0
1980	$106.8	5,073,079	1,184,111	118,411	$12,646	$2,909
1981	$114.2	5,686,163	1,797,195	179,720	$20,524	$4,721
1982	$119.4	4,842,865	953,897	95,390	$11,390	$2,620
1983	$118.6	6,075,101	2,186,133	218,613	$25,928	$5,963
1984	$113.4	7,740,504	3,851,536	385,154	$43,676	$10,046
1985	$113.5	9,325,230	5,436,262	543,626	$61,702	$14,191
1986	$111.0	10,307,954	6,418,986	641,899	$71,251	$16,388
1987	$106.7	10,775,461	6,886,493	688,649	$73,479	$16,900
1988	$102.8	10,300,079	6,411,111	641,111	$65,906	$15,158
1989	$100.7	14,593,443	10,704,475	1,070,448	$107,794	$24,793
1990	$98.7	15,434,271	11,545,303	1,154,530	$113,952	$26,209
1991	$97.9	15,966,444	12,077,476	1,207,748	$118,238	$27,195
1992	$96.7	16,137,962	12,248,994	1,224,899	$118,448	$27,243
1993	$96.1	16,788,565	12,899,597	1,289,960	$123,965	$28,512
1994	$93.9	15,535,453	11,646,485	1,164,649	$109,360	$25,153
1995	$91.7	13,378,258	9,489,290	948,929	$87,017	$20,014
1996	$89.6	14,328,684	10,439,716	1,043,972	$93,540	$21,514
1997	$87.9	14,726,102	10,837,134	1,083,713	$95,258	$21,909
1998	$85.5	14,773,918	10,884,950	1,088,495	$93,066	$21,405
1999	$83.0	14,827,013	10,938,045	1,093,805	$90,786	$20,881
2000	$83.3	14,093,158	10,204,190	1,020,419	$85,001	$19,550
2001	$87.2	13,740,501	9,851,533	985,153	$85,905	$19,758
2002	$84.8	14,491,310	10,602,342	1,060,234	$89,908	$20,679
2003	$85.8	14,424,231	10,535,263	1,053,526	$90,393	$20,790
2004	$85.3	14,810,975	10,922,007	1,092,201	$93,165	$21,428
2005	$88.3	14,691,745	10,802,777	1,080,278	$95,389	$21,939
2006	$93.5	14,568,029	10,679,061	1,067,906	$99,849	$22,965
2007	$93.3	14,637,213	10,748,245	1,074,825	$100,281	$23,065
2008	$98.2	14,859,238	10,970,270	1,097,027	$107,728	$24,777
Total NB, Undiscounted						$548,675

Notes: Cols 2 and 3 sourced from EIA by Gallaher, et al. (2010); Col 4= from Col 3, energy in each year after 1979, minus energy generated in 1979; Col 5=Col 4 energy amount x 10%; Col 6= price in Col 2 times the energy amounts in Col 5; and Col 7= DOE attribution rates for TOUGH (80%) and for other reservoir model development (20%). Increased capital costs due to use of the reservoir models offset some of the benefits. These are not included in Table II-6 for greater ease in exposition, but they are included in the benefit-cost study by Gallaher, et al. (2010).

►Treat qualitatively any economic effects of the selected technologies not captured by the quantitative economic assessment, as well as any economic effects realized from the remaining part of the cluster

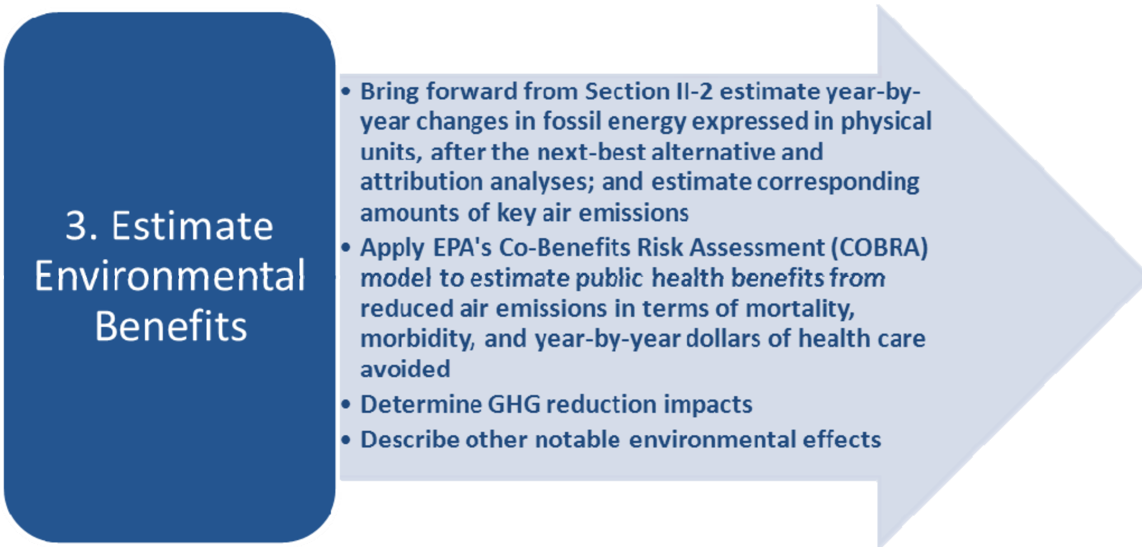
As noted previously, not all economic effects can be quantified. Some can be quantified but with great difficulty or with controversial results, while others can be quantified, but not necessarily in dollars. Economic effects not quantified in dollars are omitted from the economic return measures. Steps should be taken to include these effects as part of the overall findings, such that a judgment can be applied if there are conflicts between the results of the quantified economic performance measures and the non-quantified or non-monetized economic effects.

When there are known non-quantified or non-monetized effects omitted from the economic performance measures, OMB Circular A-4 recommends performing a "threshold" analysis to evaluate their significance. Threshold or "break-even" analysis addresses the question, "How small or how large could the value of the non-quantified or non-monetized effects be before it would offset the economic value from the quantified benefits?”

Providing explicit treatment of energy, environmental, security, and knowledge benefits within the EERE benefit-cost framework is expected substantially to reduce this problem of important effects being omitted from the analysis. Nevertheless, there may be important effects that are not captured in any of the four categories of benefits that should be considered.

Furthermore, the study approach is designed to capture only the benefits of selected technologies quantitatively. It is important, therefore, to provide a qualitative treatment of remaining elements—at minimum providing evidence that there is nothing in the cluster that will likely offset the dollar benefits of the selected technologies, or reduce confidence in the results.

3. Estimate Environmental Benefits



►Bring forward from Section II-2 estimated year-by-year changes in fossil energy expressed in physical units, after the next-best alternative and attribution analyses; and estimate corresponding amounts of air emissions.

The estimate of environmental benefits began in the previous section with the determination of changes in fossil-fuel consumption (i.e., coal, natural gas, and petroleum), reflective of the next-best alternative and attribution analyses. The year-by-year changes expressed in physical units by type of fuel are brought forward, and the corresponding amounts of air emissions are estimated for each fuel type.
Estimating emissions avoided may be assisted by the use of emission factors. An emissions factor is a representative value of the quantity of a given pollutant released to the atmosphere in association with using a designated fuel in a given activity. Emission factors are typically expressed as pounds per MWh of electricity produced for different generating sources, including natural gas, coal, oil, nuclear energy, municipal solid waste, hydropower, and a variety of renewable energy sources.

Examples of emission factors, provided by the U.S. Environmental Protection Agency (EPA) are in Table II-7. They are estimates of average emission rates from various fossil fuels used to generate electricity.

Table II-7. Emission Factors, Based on Average Emissions Rates from Fossil Fuels Used to Generate Electricity

Fossil Fuel Type	CO_2	SO_2	NO_x
Coal	2,249 lbs/1,000 kWh	13 lbs/1,000 kWh	6 lbs/1,000 kWh
Natural Gas	1,135 lbs/1,000 kWh	0.1 lbs/1,000 kWh	1.7 lbs/1,000 kWh
Petroleum	1,672 lbs/1,000 kWh	12 lbs/1,000 kWh	4 lbs/1,000 kWh

Source: EPA-issued emission factors for coal, natural gas, and oil, respectively, were found within the text at http://www.epa.gov/cleanenergy/energy-and-you/affect/coal.html; http://www.epa.gov/cleanrgy/energy-and-you/affect/natural-gas.html; and http://www.epa.gov/cleanenergy/energy-and-you/affect/oil.html.
Note the use of the following abbreviations: carbon dioxide (CO_2); sulfur dioxide (SO_2), nitrogen oxide (NO_X), http://www.epa.gov/cleanenergy/energy-and-you/affect/oil.html

Software and tools for accessing information on EPA's air emission factors can be found at http://epa.gov/ttn/chief/software. EPA's eGRID comprehensive inventory of environmental attributes of electric power systems provides percentage use of multiple energy sources to generate electricity, aggregated data by state, by company, by electric grid district, and for the nation. CO_2 emission rates can also be found at http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2010V1_1_year07_GHGOutputrates.pdf.

It is recognized that the science of assessing the impacts of various types of emissions and of multi-pollutant exposures is still under development, and new and improved models of assessment and prediction are emerging. Evaluators are encouraged to obtain and use the best available data and approaches for estimating changes in greenhouse gas (GHG) and air emissions.

►Apply EPA's Co-Benefits Risk Assessment (COBRA) Model to estimate public health benefits from reduced air emissions in terms of mortality, morbidity, and year-by-year dollars of health care avoided

EPA's Co-Benefits Risk Assessment (COBRA) model has been adopted by the EERE benefit-cost approach to provide first-order estimates of health effects and the economic value of health costs avoided resulting from changes in air emissions. The COBRA model has been used by EPA for regulatory analysis, such as for the Regulatory Impact Analysis of the Clean Air Interstate Rule (U.S. EPA, 2005).[19] Use of the COBRA model

[19] For a detailed discussion of studies used for health impact functions and unit values, see U.S. EPA (Environmental Protection Agency). (2005, March). *Regulatory impact analysis for the final Clean Air Interstate Rule*. EPA-452/R-05-002. Research Triangle Park, NC: Office of Air Quality Planning and Standards; Emission, Monitoring, and Analysis Division and Clean Air Markets Division. Available at http://www.epa.gov/cair/pdfs/finaltech08.pdf.

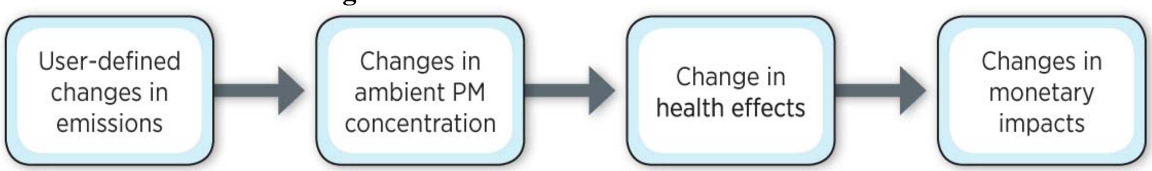
enables the health impact functions and the unit economic values used in our benefit-cost studies to be consistent with prior EPA analyses.

The COBRA Model is available on request from EPA, in the form of downloadable software and a user manual. (U.S. EPA *User's manual for the Co-Benefits Risk Assessment (COBRA) screening model*. Developed by Abt Associates Inc., June 2006.)

The model enables selection of air pollutants by type. The changes in pollutants by type are entered either as a percentage reduction (or increase) or as number of tons reduction (or increase). If the technology being evaluated is concentrated in several states, specific states can be selected within COBRA. If the technology's application is more widespread, the option of using "all states" can be selected. The model displays results in terms of change in the number of annual cases of respiratory deaths, illnesses by type, and associated costs.

At the core of the COBRA model is a source-receptor (S-R) matrix that translates changes in emissions to changes in particulate matter (PM) concentrations. The changes in ambient PM concentrations are then linked to changes in mortality risk and changes in health incidents that lead to health care costs and/or lost workdays. Figure II-3 provides an overview of the modeling steps.

Figure II-3. COBRA Model Overview



Source: EPA (2006)

In addition to entering changes in emissions, the user identifies the economic sector in which the emissions are reduced. The specified economic sector drives the underlying spatial distribution of emissions and the characteristics of the affected human population. The model then calculates the incidence of human health effects using a range of built-in health impact functions and estimated baseline incidence rates for each health endpoint. Table II-8 shows the different health endpoints that are provided by the model.

Table II-8. Health Endpoints Included in COBRA

Health Effect	Description/Units
Mortality	Number of deaths
Chronic bronchitis	Cases of chronic bronchitis
Nonfatal heart attacks	Number of nonfatal heart attacks
Respiratory hospital admissions	Number of cardiopulmonary-, asthma-, or pneumonia-related hospitalizations
Cardiovascular related hospital admissions	Number of cardiovascular-related hospitalizations
Acute bronchitis	Cases of acute bronchitis
Upper respiratory symptoms	Episodes of upper respiratory symptoms (runny or stuffy nose; wet cough; and burning, aching, or red eyes)
Lower respiratory symptoms	Episodes of lower respiratory symptoms: cough, chest pain, phlegm, or wheeze
Asthma emergency room visits	Number of asthma-related emergency room visits
Minor restricted activity days	Number of minor restricted activity days (days on which activity is reduced but not severely restricted; missing work or being confined to bed is too severe to be MRAD).
Work days lost	Number of work days lost due to illness

Source: COBRA User Manual

COBRA health effects are modeled individually based on epidemiological studies and functional forms, as described in the COBRA user's manual. For instance,

- **Mortality** risk estimates in COBRA are from an epidemiological study of the American Cancer Society cohort conducted by Pope et al. (2002). COBRA includes different mortality risk estimates for both adults and infants. Reductions in the risk of premature mortality are monetized using value of statistical life (VSL) estimates. Because of the high monetary value associated with prolonging life, mortality risk reduction is consistently the largest health endpoint valued in the study.

- **Chronic bronchitis** reflects results of a study by Abbey et al. (1995), that found statistically significant relationships between $PM_{2.5}$ and PM_{10} and chronic bronchitis.

- **Nonfatal heart attacks** are linked by Peters et al. (2001) to PM exposure.

- **Hospital admissions** include respiratory and cardiovascular, and are based on Sheppard et al. (1999) findings of asthma hospital admissions associated with PM, carbon monoxide (CO), and ozone, and findings of Moolgavkar (2000 and 2003) and Ito (2003) regarding a relationship between hospital admissions and PM.

- **Acute bronchitis** is modeled based on findings of a study by Dockery et al. (1996), that found episodes to be related to sulfates, particulate acidity, and, to a lesser extent, PM.

- **Upper respiratory symptoms** are modeled on finding of Pope et al. (2002) of a relationship between PM and the incidence of a range of minor symptoms.

- **Lower respiratory symptoms** are modeled on findings of Schwarz and Neas (2000) focused primarily on children's exposure to pollution from parental smoking and gas stoves.

- **Asthma related emergency room visits** are primarily associated with children under the age of 18, and modeled on findings of a study by Norris et al. (1999) that found significant associations between asthma ER visits and PM and CO.

- **Minor restricted activity days (MRAD)** in COBRA are based on research by Ostro and Rothschild (1989) using a national sample of the adult working population, aged 18 to 65, in metropolitan areas.

- **Work loss days** are modeled on findings of a study by Ostro (1987) which found that 2-week average PM levels were significantly linked to work loss days.

COBRA translates the health effects into changes in monetary impacts using per-unit monetary values described in the COBRA user's manual. Estimation of the monetary unit values vary by the type of health effect.

COBRA is expected to provide a conservative estimate of the health benefits of reducing air emissions for two reasons: (1) COBRA does not include the effects of many pollutants that may negatively affect health, and (2) COBRA does not fully capture the economic value of health effects of those pollutants that are included in the model. For instance, estimation of hospital admissions in dollars is based on cost of illness (COI) units that include the hospital costs and lost wages of the individual but do not capture the social (personal) value of pain and suffering.

Evaluators are to show in tables, first, the detailed mortality and morbidity data and associated costs avoidance for a selected year; and, second, the year-by-year heath care cost savings, and the undiscounted total. The first table is illustrated by the example in Table II-9 produced by application of the COBRA model in the ACE Benefit-Cost Study by Link (2010).

Table II-9. Illustration of Health Cost Calculations Results from the COBRA Model, Year 2000

(1) Category of Health Benefit	(2) Incidence	(3) Monetary Value of Health Impacts (millions $2008)
Mortality	531	$3,373.2
Infant Mortality	1	$9.1
Chronic Bronchitis	357	$158.2
Non-fatal Heart Attacks	836	$91.9
Respiratory Hospital Admissions	125	$1.7
Cardio-vascular Related Hospital Admissions	258	$7.2
Acute Bronchitis	883	$0.38
Upper Respiratory Symptoms	7,899	$0.24
Lower Respiratory Symptoms	10,473	$0.20
Asthma Emergency Room Visits	466	$0.17
Minor Restricted Activity Days	438,832	$26.8
Work Loss Days	74,012	$6.0
Total		$3,675.1

Source: COBRA model results from Link (2010).

The example continues in Table II-10, with year-by-year fuel savings, associated air pollutants, and monetary value of health impacts for the ACE Benefit-Cost Study (Link, 2010).

It should be noted that showing both estimates of changes in health incidents and associated health care costs entails double counting. However, these are kept separate in the study. The year-by-year health care cost savings are carried forward, together with economic benefits, to Step 6, and both are reflected in the bottom-line economic performance measures. The health incident data are used to explain what underlies the health care cost savings.

Using COBRA to estimate health benefits in dollar terms from reduced air pollution is deemed by experts in the field to provide sufficiently credible monetary estimates to warrant the approach of carrying the estimates forward and combining them with economic benefits to compute overall measures of economic performance (e.g., net present value benefits, benefit-to-cost ratios, and internal rate of return) in Step 6.

Table II-10. Health Benefits from Reduced Environmental Emissions from the ACE R&D Sub-Program's Research on Laser and Optical Diagnostics and Combustion Modeling (rounded), year-by-year

(1) Year	(2) Reduced Fuel Consumption with ACE R&D Sub-Program's Technologies (million gallons)	(3) PM (g/hp-hr) per EPA Regulations	(4) NO_x (g/hp-hr) per EPA Regulations	(5) SO_x (ppm) per EPA Regulations	(6) Monetary Value of Health Impacts (millions $2008)
1995	1,017	0.1	5.0	500	$2,597.8
1996	1,040	0.1	5.0	500	$2,681.1
1997	1,005	0.1	5.0	500	$2,615.8
1998	1,069	0.1	4.0	500	$2,435.4
1999	1,426	0.1	4.0	500	$3,278.1
2000	1,545	0.1	4.0	500	$3,675.1
2001	1,508	0.1	4.0	500	$3,623.5
2002	1,469	0.1	2.5	500	$2,735.7
2003	1,205	0.1	2.5	500	$2,263.4
2004	1,228	0.1	2.5	500	$2,327.9
2005	1,609	0.1	2.5	500	$3,078.0
2006	1,698	0.1	2.5	500	$3,279.0
2007	1,733	0.01	1.2	500	$1,114.0
Total	17,552				$35,704.8

Source: COBRA model; Link (2010).

►Determine GHG reduction impacts

The primary GHG to be accounted for in the benefit-cost analysis—and the only one required—is carbon dioxide (CO_2), provided in physical units. It is not monetized in current studies subject to this Guide.

The value of GHG is not expressed in monetary terms because the current value for social cost of carbon (SCC) is considered too uncertain. The range of confidence is too wide to provide useful quantification as an economic metric.

The current SCC value reported in the United States results from a 2009 effort by an interagency team of U. S. government specialists to estimate it. The result was a range of values from $5 to $65 per metric ton of carbon dioxide, with a "central value" of $21.[20]

When further improvements in the estimation of the SCC are made, and the range of estimate narrowed, GHG could be included in the benefit-cost studies as an additional metric valued in dollars, to be combined with the economic and health care cost savings and used to compute economic performance metrics. At this time, the advice of the review panel is to report GHG emissions in physical units and avoid increasing the degree of uncertainty of the economic performance measures.

►Describe other notable environmental effects

If there are other notable environmental effects other than air emissions—e.g., changes in water consumption, water discharges, land resource use, and solid waste generation—provide a qualitative treatment. If quantitative data are available, provide them together with a commentary description and explanation.

For indications of how the use of different energy generating sources may differentially affect the water and land environment, evaluators may wish to consult information compiled by the EPA. By generating source--such as natural gas, coal, oil, municipal solid waste, biomass, land-fill gas, nuclear energy, hydropower, wind, geothermal, and solar--effects on water, water discharges, land resource use, and solid waste generation are discussed.[21]

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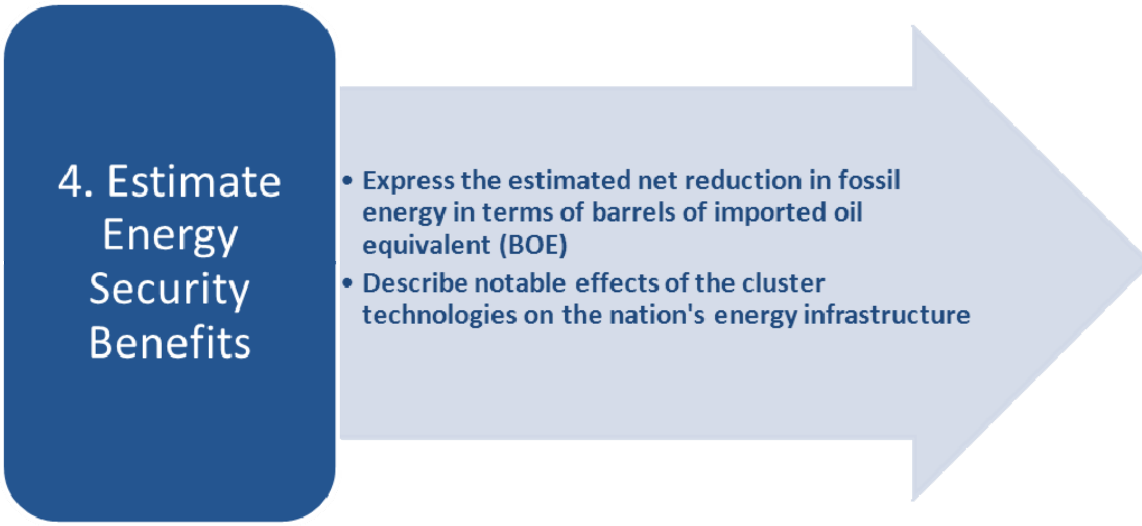
[20] An economic model, "integrated assessment model" (IAM), was used by the U.S. team to estimate the value of the SCC. The model incorporates knowledge from a number of fields of study, such as engineering, technology, behavior, and climate science, and uses mathematical formulas to simulate the relationships between economic activity and measures to control emissions and the desired environmental outcomes. Higher SCC numbers have been estimated by others, such as the UK's range of $41 – $124 per ton of CO2 with a central value of $83. The correct valuation remains controversial. For more information, see Interagency Working Group on Social Costs of Carbon (2010), and Bell and Callan (2011).

[21] As a starting point, one can find such information on-line at www.epa.gov/cleanenergy/energy-and-you/affect/index.html, under the heading "How does electricity affect the environment?"

4. Estimate Energy Security Benefits



Energy security benefits result from reducing disruptions in energy supply. They also result from reducing threats to the nation's energy infrastructure.

The energy security benefits included in the EERE approach take into account the following components:

- Quantitative estimates in physical units of reductions in barrels of oil equivalent (BOE) units of displaced imported fossil fuel as a proxy for a reduced dependence on imported energy supplies.

- Qualitative treatment of altered threats to the energy infrastructure.

►Express the estimated net reduction in fossil energy in terms of imported barrels of oil equivalent (BOE)

This estimation of reduction in BOE is driven by net reductions in fossil energy use in physical units, as calculated in Step 2. The estimation is accomplished in the following steps:

(1) Bring forward from Section 2 any estimated net reductions in fossil energy use expressed in physical units by type of energy. These fossil fuel estimates should be after the next-best alternative and attribution analyses.

(2) Translate reductions in fossil energy use into barrels of oil equivalent units, taking into account the energy source or mix of sources, and aggregating barrels across sources. Multiply by the percentage of U.S BOE demand that is imported, to reflect the share of BOE reduction associated with U.S. imported supply of oil.

Currently this share is approximately 50%.[22] Rather than apply year-by-year percentages, evaluators can use the share in the cut-off year for the benefit-cost study.

Barrels of oil equivalent is utilized as a recognizable unit of energy that serves as an indicator of national energy security benefits from reducing the quantity of imported oil. A barrel of oil equivalent (BOE) is based on the approximate energy released by burning a barrel of crude oil, where a barrel is defined as containing 42 gallons (approx. 159 liters) of crude. In terms of BTUs, one BOE is defined as 5.8 million BTU or 1,700 kilowatt hours or 1.7 MWh.

Table II-11 shows BOEs of common fossil fuels, including coal, natural gas, gasoline, and diesel fuel. It, or a similar conversion table, may be used to convert the quantity reductions in each type of fossil fuel to its BOE. Then, the imported share is taken as described above, and the results are summed for total BOE and displayed in the study report in tabular format.

Table II-11. Energy Conversion Table for Estimating BOE

British Thermal Units (Btu)	Cubic Feet Natural Gas (CF)	Short Tons Bituminous Coal (T)	Gallons of Gasoline (Gal)	Gallons of Diesel (Gal)	Barrels of Oil Equivalent (BOE)
5.8 Million	5,642	0.29	46.77	41.73	1.0

Source: Based on statements of BTU contents of common energy units provided by EIA.
Note: The heat content of crude oil varies among countries from about 5.6 MBtu per barrel to about 6.3 MBtu. Thus 5.8 MBtu is a nominal conversion factor widely used in the United States. Similarly the heat content of coal varies by type and region.

Energy security results should also be expressed in units, billions of gallons of gasoline equivalent (GGE) and millions of cubic feet of natural gas, for the appropriate fuel.

►Describe notable effects of the cluster technologies on the nation's energy infrastructure

In some cases, the program cluster evaluated may have implications for the security of the nation’s energy infrastructure. For example, use of a distributed renewable energy source may reduce the vulnerability of central power plants to disruptions. If so, provide a qualitative description of the nature of these effects and provide supporting evidence.

The monetary valuation of energy security benefits from reductions of BOEs is not included in the assessment. It is recognized that associations among changes in energy

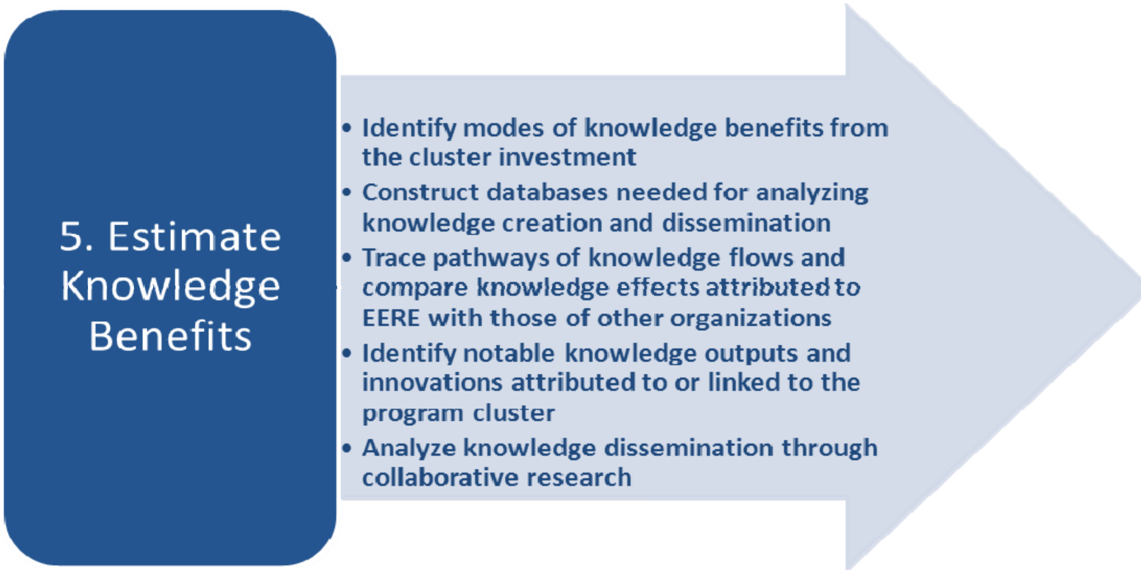
[22] According to EIA, 60% of U.S. crude oil was imported in 2005, and this share had dropped to 51% in 2009 and to 49% in 2010.

efficiency, energy supply, energy prices, and security impacts involve many assumptions, with causal relationships far more uncertain than for those entailed in estimating economic, environmental, and knowledge benefits.

Although attempts have been made by others to value in dollars the energy security benefits of achieving a given reduction in oil consumption, a satisfactory existing approach has not been identified for calculating the marginal change in the nation's energy security benefits as a result of specified percentage reduction in equivalent oil consumption.

Thus, attempts at monetary valuation of energy security benefits would be subject to far greater margins of error than for the retrospective monetary estimates of economic benefits and health care cost savings from avoided air emissions. The introduction of greater uncertainty in the monetary valuations would compromise the bottom-line benefit-cost results. For this reason, and based on recommendations of the Expert Panel which reviewed the Benefit-Cost Evaluation Methodology set forth in this Guide, the decision is to avoid monetary estimates of energy security benefits at this time—until an improved valuation approach is developed. Until then, reductions in physical units of imported BOEs, together with qualitative treatments of infrastructural effects will serve as an indicator of energy security benefits.

5. Estimate Knowledge Benefits



Two motivations drive the estimation of knowledge benefits in these benefit-cost studies:

(1) Additions to the nation's scientific and technical knowledge bases from R&D have a value far beyond the impacts that can be captured in monetary terms. To include knowledge benefits as an explicit component of R&D benefits is to recognize the larger and enduring impact of R&D on innovation and economic growth.

(2) One of the more challenging aspects of benefit-cost analysis of public R&D programs is adequately assessing attribution. By tracing from specific knowledge outputs of these evaluated programs to downstream innovations and commercial developments, the influence of the R&D is documented. This analysis, therefore, is expected to contribute to multiple lines of evidence in assessing attribution in Step 2.

►Identify modes of knowledge benefits from the cluster investment

Knowledge outputs of R&D programs are typically embodied in papers, patents, presentations, computer-based algorithms and other computational models and tools, prototypes and demonstration systems, test results, and standards; in humans—including students, professors, administrators, and researchers; and eventually in goods and services. Knowledge benefits may result from both explicit and tacit knowledge outputs. An R&D Program may contribute to the development of knowledge networks as EERE program researchers interact with and fund those in companies, universities, and other organizations in the United States and abroad.

As the Griliches/Mansfield's Model (See Part I, Section 2) shows, private returns and market spillovers in a targeted industry may result as knowledge drives innovation in competitive markets. Thus, the benefits of a Program's knowledge outputs are partially captured in a benefit-cost study's estimates of economic, environmental, and security benefits.

The realized and potential benefits of knowledge, however, are likely to extend well beyond those captured in a target market. As knowledge flows into, and yields benefits in other markets, the spillover gap—i.e., the excess of social returns over private returns—continues to expand.

The separation of knowledge benefits that have already been captured in the monetary valuation of other categories of benefits from those not yet captured is complex and is not attempted in this benefit-cost approach. Rather, identifying contributions of the cluster investment to the scientific and technical knowledge bases both within and outside the targeted industry area of application is an analysis goal. As noted above, the result is a more comprehensive and quantitative assessment of knowledge benefits than was provided by previous benefit-cost studies.[23]

The pathways from R&D knowledge outputs to commercial application of these outputs are typically long and complex. Use of a historical tracing framework employing interviews with program managers, researchers, and company managers; web searches; document and database review; bibliometric analysis; and other techniques is helpful in identifying and documenting these pathways. There may be multiple decades of DOE R&D in a given program cluster area. A variety of approaches will help to avoid missing critical connections. The objective is to assess the extent to which the knowledge was both created and used to influence downstream applications, and by whom.

To provide objectively derived, quantitative evidence of linkages that can be developed in a relatively non-intrusive manner, patent citation analyses has proven particularly useful. Patents have a central role in the innovation system, are consider closer to application than publications, and, as noted by Jaffe and Trajtenberg (2005), have been used extensively in the study of technological change. Patents are in the public domain and search engines can find them.

Publication analysis has also proven useful in assessing the knowledge benefits of program cluster investment. Analysis of coauthoring by program cluster researchers with those in other organizations may show linkages through collaborative research; patent-to-scientific paper citation analysis shows early influence of laboratory research on innovation; and publication-to-publication citation analysis shows pathways of knowledge flow through publications.

[23] Past benefit-cost studies have typically not separately treated knowledge benefits. An exception was the 2001 NRC benefit-cost study. However, a limitation of the 2001 NRC study was that it defined knowledge benefits as a "catch-all" for situations in which technology development had either failed, was still under development with no commercialization in sight, or had succeeded but was expected not to be adopted because economic and policy conditions were expected never to become favorable. Hence, the EERE approach to knowledge benefits represents a much more comprehensive treatment.

►Construct databases needed for analyzing knowledge creation and dissemination

To perform patent analysis, evaluators will need to construct databases of patents derived from the cluster investment. To do this, it is necessary to search Program files, the Office of Scientific and Technical Information (OSTI) database, and databases of patent offices, such as the U.S. Patent and Trademark Office (PTO), the European Patent Office (EPO), and the World Intellectual Property Organization (WIPO), using patent filters. It has been found that companies whose R&D has received public funding do not always acknowledged the public interest when filing resulting patents, and this omission may require searches of DOE annual reports, matching of identified patents with DOE-funded company research, and verification with DOE experts. When subprograms are assessed, special attention may be needed to identify the set of patents associated with a highly focused R&D effort.

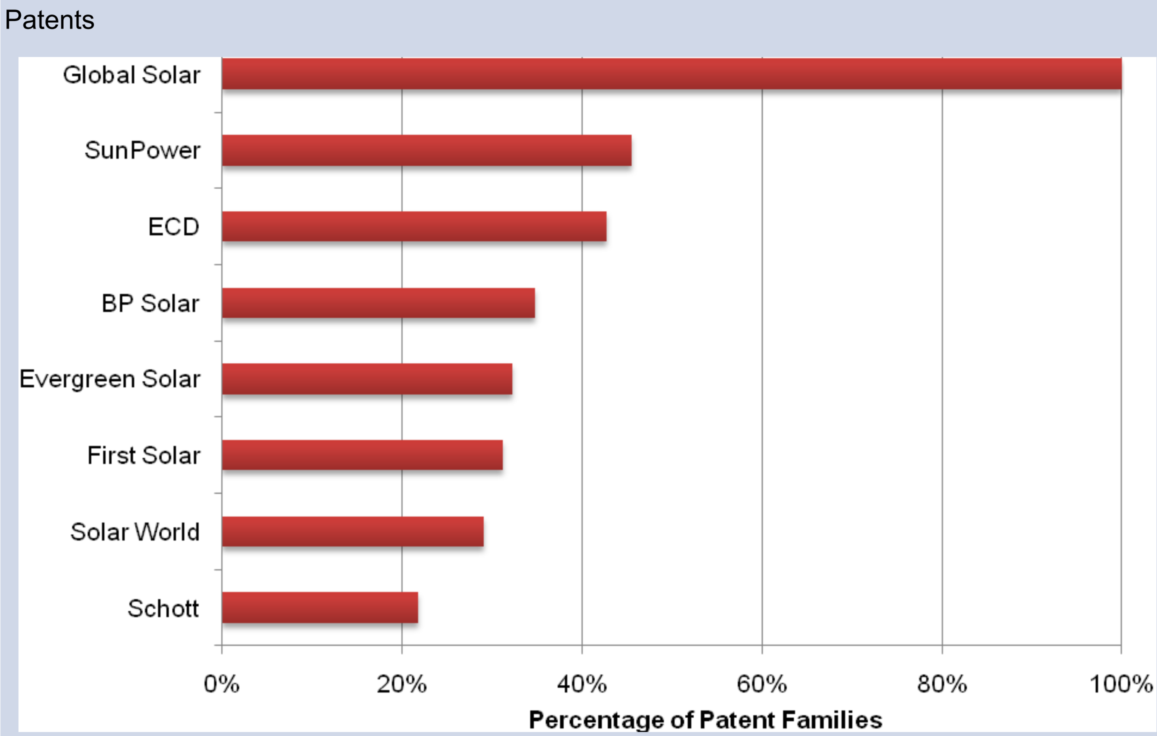
To avoid double counting of patents, evaluators will need to construct "patent families" which contain all patents based on an original patent. To perform comparisons of patenting intensity resulting from program cluster investment with that of other organizations, and to trace from commercial users back to earlier R&D sources, evaluators will need to identify relevant organizations who are innovators in the technology area of focus and their relevant patent portfolios. To provide country comparisons, relevant patent databases will need to be constructed by country of first issue. To identify highly significant patents, evaluators will need to construct and use citation indices to adjust for technology area and year of issue.

►Trace pathways of knowledge flows and compare knowledge effects attributed to EERE with those of other organizations

Two main approaches are used to trace patent linkages between program cluster R&D and downstream developments. One approach—forward patent tracing—takes a broad look at downstream linkages. Its purpose is to determine the influence of program cluster patents have had on the development of downstream technologies in all areas. The other approach—backward patent tracing—focuses specifically on linkages from downstream commercial developments in the targeted industry back to patents attributable to the program cluster R&D. These analyses are performed both at the organization level and at the individual patent level.

To test the strength of linkages of program cluster attributed patents to commercial applications, perform a backward citation analysis, starting with patents of the leading innovators in the field and see to what extent they link back to patents funded by the Program cluster, as compared with the extent of linkages to other organizations. This approach is illustrated by Figure II-4, which is drawn from the solar PV knowledge benefits study by Ruegg and Thomas (2011), performed in support of the solar PV benefit-cost study by O'Connor, et al. (2010).

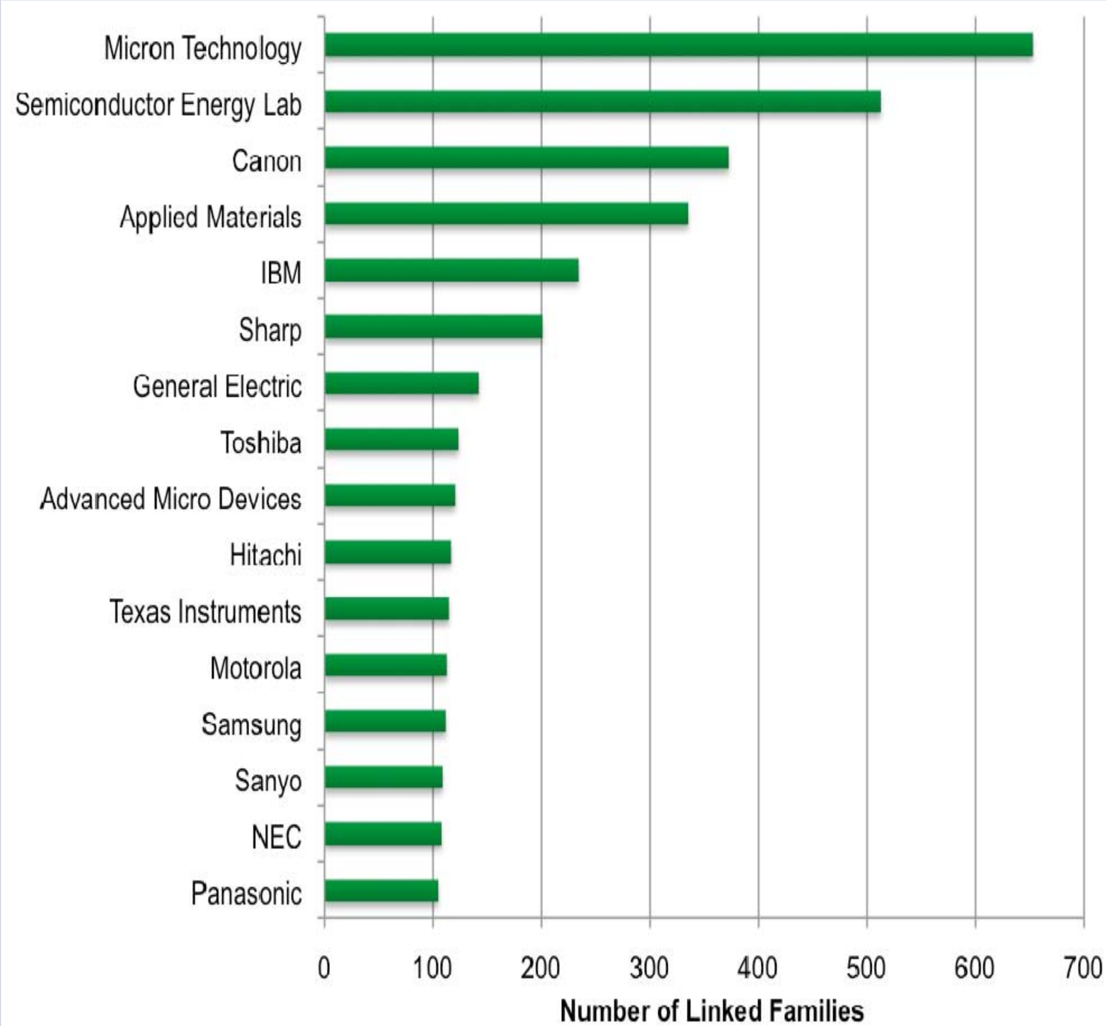
Figure II-4. Percentage of Solar Energy Patent Families of Top U.S. Solar PV Producers Linked to Earlier DOE-Attributed Solar PV



Source: Ruegg and Thomas, Solar PV (2011).

To determine linkages through patents attributed to the program cluster to not only the targeted industry but beyond to other industries, perform a forward citation analysis, starting with program-attributed patents and identifying subsequent patents that link back to these earlier program-attributed patents. An illustration of forward tracing at the organizational level is provided by Figure II-5, which is also drawn from the solar PV knowledge benefits study by Ruegg and Thomas (2011), in support of the solar PV benefit-cost study by O'Connor, et al. (2010). It highlights influence of the EERE's solar PV research beyond U.S. leading PV producers to leading companies in the semiconductor industry.

Figure II-5. Organizations from All Industry Areas with the Largest Number of Patent Families from All Technologies Linked to Earlier DOE-Attributed PV Patents



Source: Ruegg and Thomas, Solar PV (2011).

►Identify notable knowledge outputs and innovations attributed to or linked to the program cluster

A concept useful in tracing knowledge flows is that highly cited patents (i.e., patents cited by many later patents) tend to contain technological information of particular importance. A patent that forms the basis for many new innovations tends to be cited frequently by later patents.[24]

[24] This does not mean that every highly cited patent is important, or every infrequently cited patent is unimportant, but, research studies have shown a correlation between the rate of citations of a patent and its technological importance.

An example of notable (i.e., highly cited) PV innovations of companies linked back to EERE-attributed PV patents is given in Table II-12, drawn from the Ruegg and Thomas knowledge benefits study performed in support of the 2010 Solar PV Benefit-Cost Study by O'Connor, et al, 2010. The Citation Index adjusts for the type of technology and for the age of the patent, such that, for example, the Index value of 4.52 in the table's first row means that this patent (#4419533) has been cited approximately 4.5 times more often than would be expected of a patent of its age, within its technology area.

Table II-12. Highly Cited Solar Energy Patents of Top U.S. PV Producers Linked to Earlier DOE-Attributed PV Patents

Patent[a]	Issue Date	# Cites Received	Citation Index	Assignee	Title
4419533	1983	47	4.52	ECD	Photovoltaic device having incident radiation directing means for total internal reflection
5164019	1992	51	4.08	SunPower	Monolithic series-connected solar cells having improved cell isolation and method of making same
6534703	2003	12	3.12	SunPower	Multi-position photovoltaic assembly
6111189	2000	19	2.93	BP	Photovoltaic module framing system with integral electrical raceways
6353042	2002	12	2.92	Evergreen Solar	UV-light stabilization additive package for solar cell module and laminated glass applications
6570084	2003	11	2.86	SunPower	Pressure equalizing photovoltaic assembly and method
4514583	1985	31	2.82	ECD	Substrate for photovoltaic devices
4419530	1983	28	2.69	ECD	Solar cell and method for producing same
5746839	1998	30	2.64	SunPower	Lightweight, self-ballasting photovoltaic roofing assembly

Source: Ruegg and Thomas, Solar PV (2011).

Patent-to-publication citation analysis can be used to identify when a subsequent technological development has drawn more directly on a scientific base. Thus an extended feature of the patent analysis is to assess program-cluster papers and publications cited by patents as prior art. An example is provided by Table II-13, drawn from the knowledge benefits study by Ruegg and Thomas (2011).

Publication-to-publication citation analysis can also indicate notable technologies, and show pathways of knowledge dissemination.

Table II-13. EERE Geothermal Paper/Publications Linked to the largest Number of Patent Families through Two Generations of Citations

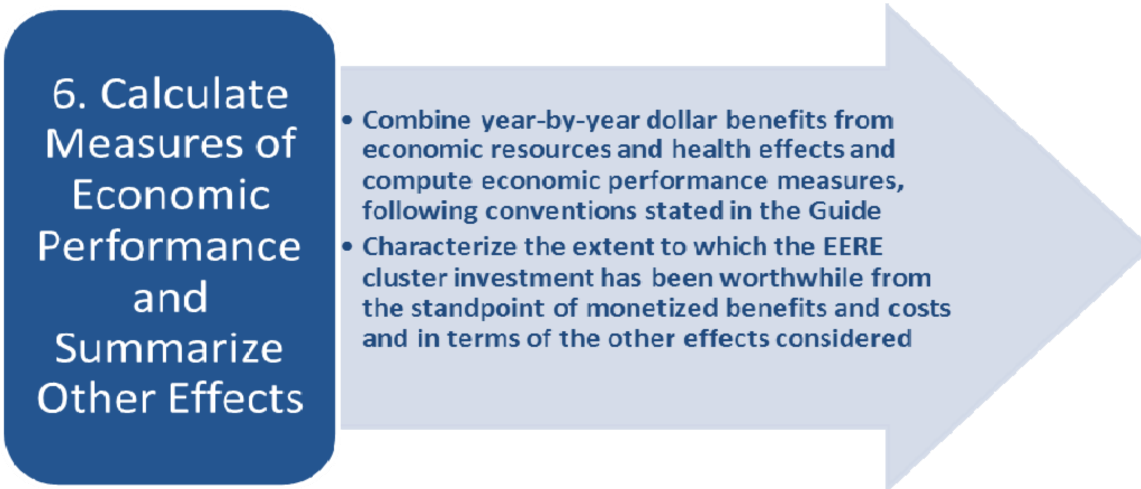
# Linked Patents	DOE Papers/Publications
203	"Interfaces and Mechanical Behaviors of Fiber-Reinforced Calcium Phosphate Cement Compositions," by T. Sugama, et al., prepared for the Geothermal Division U.S. Department of Energy; Department of Applied Science (June 1992)
197	"Microsphere-Filled Lightweight Calcium Phosphate Cements," by Sugama, T., et al., U.S. Department of Energy, Washington, D.C. under contract No. DE-AC02-76CH00016 (December 1992)
197	"Hot Alkali Carbonation of Sodium Metaphosphate Fly Ash/Calcium Aluminate Blend Hydrothermal Cements," by T. Sugama, *Cement and Concrete Research Journal*, vol. 26, No. 11, pp. 1661-1672 (1996)
192	"Calcium Phosphate Cements Prepared by Acid-Base Reaction," by Sugama, T. et al., *Journal of the American Ceramic Society*, vol. 75, No. 8, p. 2076-2087 (August 1992)
185	"Carbonation of Hydrothermally Treated Phosphate-Bonded Calcium Aluminate Cements," by T. Sugama, et al., U.S. Department of Energy, Washington, D.C. under contract No. DE-AC02-76CH00016 (Undated)
108	"Use of Single-Cutter Data in the Analysis of PDC Bit Designs: Part 1--Development of a PDC Cutting Force Model," by Glowka, D.A., *JPT*, pp. 797-799, 844-849 (August 1989)
105	"Use of Single-Cutter Data in the Analysis of PDC Bit Designs: Part II--Development and Use of PDCWEAR Computer Code," by Glowka, D.A., *JPT*, pp. 850-859 (August 1989)
101	"Acoustical Properties of Drill Strings," by Drumheller, D., *The Journal of the Acoustical Society of America*, No. 3, New York, pp. 1048-1064 (March 1989)
56	"The Propagation of Sound Waves in Drill Strings," by Drumheller, D., et al., *The Journal of the Acoustical Society of America*, No. 4, pp. 2116-2125 (April 1995)
37	"Acoustical Properties of Drill Strings," by Drumheller D, Sandia National Laboratories, SAND88 0502 (August 1988)
32	*Sourcebook on the Production of Electricity from Geothermal Energy*, Kestin, J., editor, Publication No. DOE/RA/4051, Chap. 4, p. 536 (1980)

Source: Ruegg and Thomas, Geothermal (2011).

►Analyze knowledge dissemination through collaborative research

Linkages from the R&D of program clusters are also assessed and demonstrated through the analysis of publication coauthoring, and the identification of networks that have formed among individuals, organizations, associations, and other groups involved in an R&D effort and the use of R&D outputs.

6. Calculate Measures of Economic Performance and Summarize Other Effects



►Combine year-by-year dollar benefits from economic resources and health cost effects and compute economic performance measures, following conventions stated in the Guide.

Bring forward the year-by-year series of economic benefits (undiscounted) from Step 2 and the year-by-year series of health care benefits (undiscounted) from Step 3. Show the year-by-year series separately and also combined. Table II-14 gives an example from a recent benefit-cost study.

Calculate the economic performance measures for the two data series separately and combined, using the formulas given in Part I, Figure I-2.

Spreadsheet functions or similar computational tools can be used to calculate the economic performance measures, provided their use satisfies the set of conventions listed in Table II-15. (An EERE goal is that consistency be followed across the set of EERE benefit-cost studies.)

An example of the bottom-line economic performance measures is given in Table II-16 A and B, from the ACE R&D Benefit-Cost Study by Link (2010).

Table II-14. Economic Benefits of Reduced Fuel Consumption, Monetary Value of Health Impacts, and Total economic benefits from the 2010 ACE R&D benefit-cost study

Year	Dollar Value of Reduced Fuel Consumption (millions $2008)	Monetary Value of Health Impacts (millions $2008)	Total Economic Benefits (millions $2008)
1995	$1,502.0	$2,597.8	$4,099.8
1996	$1,683.7	$2,681.1	$4,364.8
1997	$1,547.3	$2,615.8	$4,163.1
1998	$1,410.7	$2,435.4	$3,846.1
1999	$1,996.8	$3,278.1	$5,274.9
2000	$2,817.2	$3,675.1	$6,492.3
2001	$2,526.5	$3,623.5	$6,150.0
2002	$2,283.6	$2,735.7	$5,019.3
2003	$2,097.7	$2,263.4	$4,361.1
2004	$2,491.7	$2,327.9	$4,819.6
2005	$4,189.2	$3,078.0	$7,267.2
2006	$4,834.5	$3,279.0	$8,113.5
2007	$5,115.4	$1,114.0	$6,229.4
Total	$34,496.4	$35,704.8	$70,201.1

Source: Link, 2010

Table II-15. Summary of Conventions for Computing Economic Performance Measures

- **Discount Rate**: 7% and a 3% real discount rates are to be used per OMB Circulars A-94 and A-4 pertaining to benefit-cost analysis, respectively, and the sensitivity of economic performance results will be displayed for 0% (undiscounted case), 3%, and 7% discount rates.

- **Base Year** (time to which all cash amounts are converted in a present value analysis): The base year to be used marks the onset of cash flow, which for the cluster economic performance measures is the year in which the investment in the technology cluster began.

- **Cash-Flow Modeling Conventions**: Cash flows are to be expressed annually and can be modeled as though they occur at the end of the year. A common practice in cash flow analysis is to model investment costs as occurring at the beginning of each year and benefits net of operating and maintenance costs as occurring at the end of each year. However, built-in formulations of popular spreadsheet program tend not to make this distinction automatically and require that the Evaluator to adjust the designated timing of investment cash flows, which is simple to do. Use of either cash-flow modeling convention is acceptable for these benefit-cost studies—that is, modeling all cash flows at the end of the year in which they occur, or, alternatively, modeling investment costs at the beginning of the year in which they occur and benefits net of operating and maintenance costs at the end of the year in which they occur. Alternatively a mid-year convention can be used. However, the study should indicate explicitly the cash-flow modeling convention is has used.

- **Constant Dollars**: All cash flows are to be converted to constant dollars as of the designated year for which $1.00 = 1.00 as found in the list of year-by-year GDP price deflator indices issued in the most recent Addendum to this Guide. (For the four EERE Benefit-Cost studies published in 2010, all current dollars were converted to constant 2008 dollars.)

- **Present Values**: All constant dollar cash flows are to be adjusted to equivalent present value amounts as of the base year (i.e., as of the year which marks the onset of cash flow).

- **Economic Performance Measures**: The three measures —NB, B/C, and IRR—in Figure I-2 and discussed in the section following are to be used to estimate the return on EERE's program investment in a defined technology cluster.

Table II-16A. ACE R&D Sub-Program and CRF Costs and Economic Benefits Associated with the ACE R&D Sub-Program's Research in Laser and Optical Diagnostics and Combustion Modeling

(1) Year	(2) Costs: ACE R&D Sub-Program (millions $2008)	(3) Costs: Combustion Research Facility (millions $2008)	(4) Total ACE R&D Costs (millions $2008)	(5) Total Economic Benefits (millions $2008)
1986	$27.402	$5.602	$33.004	–
1987	$29.005	$5.930	$34.935	–
1988	$27.785	$5.680	$33.465	–
1989	$26.525	$5.423	$31.948	–
1990	$25.929	$5.588	$31.517	–
1991	$22.869	$6.240	$29.109	–
1992	$23.611	$6.223	$29.834	–
1993	$20.550	$6.073	$26.623	–
1994	$17.587	$5.665	$23.252	–
1995	$13.890	$5.549	$19.439	$4,099.8
1996	$21.574	$6.154	$27.728	$4,364.8
1997	$24.714	$6.743	$31.457	$4,163.1
1998	$23.239	$6.547	$29.786	$3,846.1
1999	$46.230	$6.281	$52.511	$5,274.9
2000	$57.211	$5.796	$63.007	$6,492.3
2001	$62.475	$6.538	$69.013	$6,150.0
2002	$55.538	$6.332	$61.870	$5,019.3
2003	$63.714	$6.842	$70.556	$4,361.1
2004	$59.119	$6.605	$65.724	$4,819.6
2005	$52.593	$6.983	$59.576	$7,267.2
2006	$42.649	$6.567	$49.216	$8,113.5
2007	$49.379	$7.811	$57.190	$6,229.4
Total	$793.59	$137.17	$930.76	$70,201.1

Table II-16B. Example of Evaluation Performance Metrics Calculated from the Combined Economic and Health Care Benefits and the ACE R&D Subprogram Costs

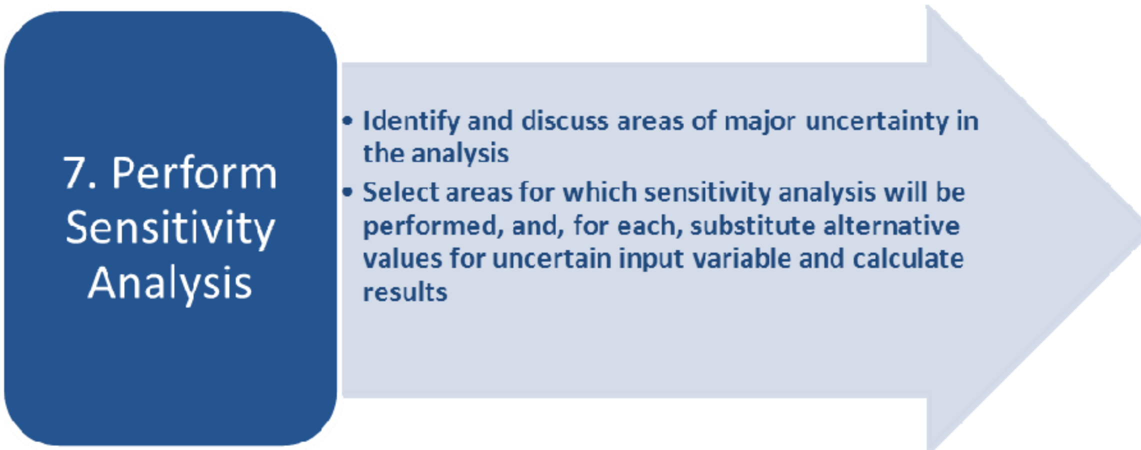
Metric	7% Discount Rate	3% Discount Rate	Internal Rate of Return
Present Value of Net Benefits (billions $2008)	$23.1	$42.6	
Benefit-to-Cost Ratio	53 to 1	66 to 1	
Internal Rate of Return			63%

Source: Link (2010).

►Characterize the extent to which the EERE cluster investment has been worthwhile from the standpoint of monetized benefits and costs and in terms of the other effects considered

The tests for using the various economic performance metrics to determine if an investment has been worthwhile are noted in Part I, section 2, ("Economic Performance Measures"). These simple tests are that the NPV is positive; that the BCR is greater than one; and that the IRR is greater than the required rate of return (as indicated by the OMB-specified discount rate). The extent to which an investment has been economically worthwhile is signaled by the size of these measures—the larger the measure, the more economically worthwhile the investment has been up to the evaluation cut-off year, others factors being equal. However, it is to be remembered that these economic metrics are based on partial benefits. Their implications for how worthwhile an investment has been are conservative and need to be conditioned by the other impacts which were not included in the metrics.

7. Perform Sensitivity Analysis



Previously acknowledged is that multiple discount rates are required by the Guide to calculate the economic performance measures: discount rates of 0%, 3%, and 7% (See Part 2, Step 2). In effect, use of the multiple rates will show sensitivity of the results to the discounts rate.

Some other input variables may have been expressed using multiple values, such as a range of possible values. Other input variables may have higher degree of uncertainty surrounding them. Uncertainties in the evaluation need to be explicitly acknowledged and treated.

►Identify and discuss areas of major uncertainty in the analyses, such as the following:

- When a range of implied or explicit values were obtained for an input variable;
- When an alternative estimation approach could have been justified for use, and its use is expected to have produced different results than the approach taken; and
- When a given input variable or assumption is expected to have a large effect on outcome, and there is uncertainty about it.

►Select areas for which sensitivity analysis will be performed, and, for each, substitute alternative values for uncertain input variable and calculate results

- To test sensitivity of results to a range of input values, use the low and high ends of the range to generate a range of outcomes. (See Example A below, Table II-17)

- To test the sensitivity of results to a different estimation approach for a key input variable, go back to the stage of the analysis in which the key input first appears and recalculate it using the alternative approach; then feed the results through all subsequent affected calculations. (See Example B below, including Tables II-18 and II-19)

Sensitivity Analysis--Example A: Table II-17. Sensitivity to Variation in Acceleration Effect and Discount Rate

Measure	12-year Acceleration Effect	10-year Acceleration Effect	15-year Acceleration Effect
Net benefits (billion 2008$)	$15.03	$10.68	$22.17
Internal rate of return	17%	14%	20%
NPV @ 7% (billion 2008$; base year = 1975)	$1.46	$0.86	$2.39
Benefit-to-cost ratio @ 7%	1.83	1.49	2.37
NPV @ 3% (billion 2008$; base year = 1975)	$5.72	$3.99	$8.53
Benefit-to-cost ratio @ 3%	3.24	2.56	4.35

Source: O'Connor, et al. (2010)

Sensitivity Analysis--Example B: Test the Sensitivity of Results to a Different Estimation Approach

The test is for sensitivity to the way the energy savings were calculated. Initially they were calculated based on a statistical relationship found between brake thermal efficiency (BTE), a measure of fuel efficiency, and resulting miles per gallon (MPG), based on the period 1970-2007, and this relationship was assumed to apply to the period 1995-2007. In the initial analysis, this statistical relationship resulted in 17.6 billion gallons of diesel fuel oil saved from 1995 through 2007, with an IRR of 63%.

The alternative approach assumed that new heavy-duty diesel trucks would each year consume a proportionate amount of fuel each year and that proportion would remain constant over time. The sensitivity analysis showed that using the alternative method of calculating energy savings resulted in 15.1 billion gallons of diesel fuel oil saved, and an IRR of 50%. Results on energy savings and on the bottom-line economic performance measures from using the alternative approach to estimating energy savings are shown in Tables II-18 and II-19.

Table II-18. Sensitivity Testing of Reduced Fuel Consumption from the ACE Subprogram R&D Using an Alternative Method (Link, 2010)

Year	Reduced Fuel Consumption with ACE R&D Sub-Program's Technologies (million gallons)	Average Retail Price Diesel Fuel (per gallon)	Dollar Value of Reduced Fuel Consumption (millions $)	GDP Implicit Price Deflator (2008=100)	Dollar Value of Reduced Fuel Consumption (millions $2008)	Dollar Value of Health Impacts (millions $2008)
1995	169.2	$1.11	$187.85	75.160	$249.94	$432.2
1996	318.5	$1.24	$394.89	76.591	$515.59	$821.1
1997	475.1	$1.20	$570.06	77.943	$731.38	$1,236.6
1998	651.0	$1.04	$677.03	78.824	$858.91	$1,483.1
1999	874.4	$1.12	$979.28	79.983	$1,224.37	$2,010.1
2000	1,067.6	$1.49	$1,590.67	81.715	$1,946.61	$2,539.5
2001	1,197.0	$1.40	$1,675.86	83.561	$2,005.55	$2,876.2
2002	1,314.9	$1.32	$1,735.61	84.915	$2,043.94	$2,448.7
2003	1,437.8	$1.51	$2,171.05	86.742	$2,502.88	$2,700.7
2004	1,595.4	$1.81	$2,887.74	89.203	$3,237.27	$3,024.4
2005	1,809.2	$2.40	$4,342.18	92.180	$4,710.54	$3,461.0
2006	2,038.1	$2.71	$5,523.29	95.183	$5,802.81	$3,935.8
2007	2,171.8	$2.89	$6,276.54	97.908	$6,410.65	$1,396.1
Total	15,119.9				$32,240.44	$28,365.5

Example B, continued.

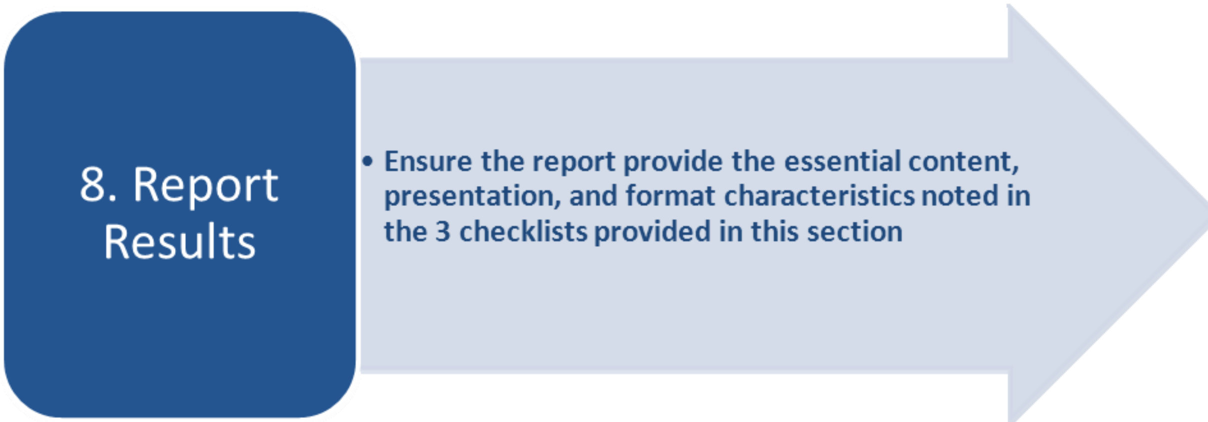
Table II-19 Evaluation Metrics for ACE Subprogram Re-Calculated to Show Sensitivity to the Alternative Assumption for Calculating Energy Savings in Table II-18

Metric	7% Discount Rate	3% Discount Rate	Internal Rate of Return
Present Value of Net Benefits (billions $2008)	$17.8	$35.0	
Benefit-to-Cost Ratio	41 to 1	54 to 1	
Internal Rate of Return			50%

Source: From Link (2010)

Note that the sensitivity testing in Example B does not say which estimation approach is better for estimating diesel fuel cost savings; it does show the results based on either calculation approach are quite strong.

8. Report Results



Goals to be achieved by Step 8 are that evaluators:

- Produce benefit-cost reports, and supporting study outputs, that will serve as effective communication tools with diverse program stakeholders about the study, its findings, and its implications.
- Maintain best practices and a level of consistency with other benefit-cost studies/reports that have similar purpose—while reflecting the unique requirements and data availability issues that evaluators typically encounter across studies.
- Produce reports whose input data, assumptions, and calculations are sufficiently transparent that they can be replicated and verified by others.
- Present data that can be added to a meta data infrastructure for EERE's benefit-cost studies which will allow for multiple, discrete packages of study data that are linked to allow aggregate calculations and that inform program data collection plans and activities.

► Ensure the study report provides essential content characteristics by following the "Contents Checklist" found in Table II-20

Table II-20. Contents Checklist

Use this column to rate each content element as: **_Found** **_Not Found** **_Adequate** **_Inadequate**	**Content Topics**	**Essential Characteristics**
	Statement of Study Design, Objectives, Approach, Nature of Findings; and Impacts Included and Excluded	• Benefit-cost framework • Cluster approach • Statement of evaluation objectives • Retrospective analysis with cut-off year and no life-cycle benefits counted • Conceptual models based in theory used • Focus on public returns only • All findings are evidence-based • Conservative, lower-bound estimates of findings, with reasons why • Clear delineation of all categories of impacts included--those with monetary valuation, those with other quantitative valuation, and those with qualitative valuation • Identification of effects excluded from the evaluation
	Description of Program Cluster Overall and Selected Technologies for Detailed Treatment	• How and why program cluster was selected • Overall description of cluster • Description of selected technologies for detailed treatment, and rationale for selection • Method of treatment for each technology (or group) separately assessed • Discussion of other elements in the cluster (not included for detailed treatment) and their likely impact on economic returns • Cost: year-by-year total cluster costs and year-by-year costs of the selected technologies

	Next-best Alternative	• Designation for each selected technology (or group) individually assessed • Description of resulting baseline used in estimating differential effects of each technology (or group) • Explicit treatment of next-best alternative, separate from attribution assessment
	Attribution Assessment	• Assessment of context in which the program operated and external influences that may constitute rival explanations of outcomes • Fully documented attribution matrix for each technology (or group) individually treated • Timeline of relevant developments • Treatment of rival explanations of outcome • Clear representation of attribution level, such as by % share of differential effect for each technology (or group) attributable to the public program cluster • Explicit treatment of attribution, separate from next-best alternative assessment
	Data Quality, Collection Tools, Uncertainties, and Exposition	• Use of valid protocols and procedures in data collection • Statement of critical assumptions • Inclusion of all data used in the analysis • Identification of data sources • Identification of uncertainties, and data distributions where relevant • Inclusion of interview and survey tools • List of interviewees
	Estimation of Each of 4 Category of Benefits--(1) Energy & Other Economic Benefits, (2) Environmental Benefits, (3) Energy Security Benefits, and (4) Knowledge	• Systematic and transparent analyses, with all steps documented, and approach/results replicable • Credible treatment of (and explanation thereof) of both demand and supply sides of the analysis, with fully documented assumptions

		• Separate treatment of: Energy Effects, including types of energy and physical quantities
	Calculation of Economic Performance Measures	• Measures include NB (undiscounted), NPV based on 3% and 7% discount rates, BCR based on 3% and 7% discount rates, and IRR • These measures are separately calculated for: (1) Energy & Other Economic benefits (2) Combined Economic and Health Cost Avoidance
	Sensitivity Analysis	• Performed to highlight effects of uncertain or controversial variables, assumptions, and estimation methods
	Overall Conclusions	• Summary of evidence-based findings • Implications of findings • Indication that all stated evaluation objectives have been achieved • Identification of study limitations

►Ensure the study report provides essential format characteristics by following the "Format Checklist" found in Table II-21

Table II-21. Format Checklist

Use this column to rate each report component as: _Found _Not Found _Adequate _Inadequate	Report Components	Description
	Title Page	• Title • Date • Prepared by... • DOE cover design

	Preface (if desired by DOE)	DOE prepared, e.g., description of mission, objectives, programs, rationale for public investment, and purposes of retrospective impact evaluation
	Acknowledgements	Contributors and reviewers
	Notice	DOE prepared
	Executive Summary	• Written for audience of diversion backgrounds, designed to communicate quickly and concisely the most important findings, conclusions, and implications • Specific inclusion of overall results summation table including the metrics included in Table I-1 of this Guide
	Table of Contents and lists of Tables and Figures	• 3-levels of headings for TOC • Electronically keyed to report sections to facilitate easy movement of the reader through the report.
	Main Body of the Report	• All elements of essential contents as outlined in Table II-20 • Separate Sections on each of the 4 categories of benefit : o Energy & Other Economic Benefits o Environmental Benefits (including GHG & Health Care Cost Savings) o Energy Security Benefits o Knowledge Benefits
	References	listing of references cited in the report; not a general reading list
	Appendices/Attachments	Supporting information that can be moved out of the main body of the report for improved readability, but that is strongly germane to the presentation and likely desired by certain readers
	Index, List of Terms, List of Abbreviations	Discretionary

►Ensure the study report provides essential presentation characteristics according to the "Presentation Checklist" found in Table II-22

Table II-22. Presentation Checklist

Use this column to rate the report's presentation according to each essential characteristic as: **_Adequate** **_Inadequate**	**Essential Presentation Characteristics**
	Concise, clear, transparent exposition
	Rigor demonstrated in data collection, analyses, and interpretation
	Document is accurate and reliable; free of errors of fact or logic
	Findings are objectively derived, testable, and reproducible
	Study has internal and external validity
	Study has credibility among stakeholders

►Use these Content, Format, and Presentation Checklists throughout the study

The checklists are intended for use by evaluators and by project managers on an on-going basis to keep the report development on track. They may also be used by report reviewers.

References

Bell, Ruth Greenspan, and Dianne Callan (2011) "More than Meets the Eye: The Social Cost of Carbon in U.S. Climate Policy, in Plain English, Policy Brief" (World Resources Institute).

Butry, D. T.; Brown, M. H., Fuller, S. K. (2007) *Benefit-Cost Analysis of Residential Fire Sprinkler Systems*, NISTIR 7451 (Gaithersburg, MD, National Institute of Standards and Technology).

Gallaher, Michael, A. Rogozhin, and J. Petrusa (2010) *Retrospective Benefit-Cost Evaluation of U.S. DOE Geothermal Technologies Program Investments: Impacts of a Cluster of Energy Technologies* (Washington DC: U.S. Department of Energy.

Griliches, Z. (1958). "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66: 419-431.

Jaffe, A. (1996) *Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program*. NIST GCR 97-708 (Gaithersburg, MD: National Institute of Standards and Technology) Available at http://www.atp.nist.gov/eao/gcr708.htm.

Jaffe, A. and Trajtenberg (2005). *Patents, Citations, and Innovations: A Window on the Knowledge Economy*. MIT Press (Originally published in 2002; reissued in 2005).

Interagency Working Group on Social Costs of Carbon (2010) "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866." In Final Rule Technical Support Document (TSD): Energy Efficiency Program for Commercial and Industrial Equipment: Small Electric Motors. Washington, DC: U.S. Department of Energy, Appendix 15A. Available at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/smallmotors_tsd/sem_finalrule_appendix15a.pdf.

Link, A.N. (2010) *An Economic Evaluation of the U.S. Department of Energy's Investments in Vehicle Combustion Engine R&D*. (Washington, D.C.: U.S. Department of Energy).

Mansfield, E., J. Rapoport, A. Romeo, S. Wagner, and G. Beardsley (1977) "Social and Private Rate of Return from Industrial Innovation," *Quarterly Journal of Economics*, 91: 221-240.

Mansfield, E. (1996). *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities*. NIST GCR

99-780 (Gaithersburg, Maryland: National Institute of Standards and Technology).

Marshall, Harold (1996) "Sensitivity Analysis", in Dorf, R. (editor) *The Engineering Handbook (CRC Press,* pp. 1962-1967).

McLaughlin, John A. and Jordan, Gretchen B. (2010, 3rd edition), "Logic Models," in Wholey, Hatry, and Newcomer (editors), *Handbook of Practical Program Evaluation* (Jossey-Bass).

National Research Council, Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy (2001) Energy Research at DOE: Was it worth it? Energy Efficiency and Fossil Energy Research 1978 to 2000 (Washington, DC: The National Academies Press, 2001. Available on-line at http://www.nap.edu/openbook.php?isbn=0309074487.

O'Connor, Rowe, Gallaher, Sevinsky, and Wood (2007) *Economic Impact of ATP's Contributions to DNA Diagnostics Technologies*, GCR 06-898 (Gaithersburg: MD, National Institute of Standards and Technology). Available at http://www.atp.nist.gov/eao/gcr06-898.pdf.

O'Connor, Alan, R. Loomis, and F. Braun (2010) *Retrospective Benefit-Cost Evaluation of DOE Investment in Photovoltaic Energy Systems*, DOE/EE-0349 (Washington DC: U.S. Department of Energy.

Pelsoci, Thomas M. (2005) *Photonics Technologies: Applications in Petroleum Refining, Building Controls, Emergency Medicine, and Industrial Materials Analysis*;, *Economic Analysis of a Cluster of ATP-Funded Projects*, NIST GCR 05-879 (Gaithersburg, MD: National Institute of Standards and Technology). Available at http://www.atp.nist.gov/eao/gcr05-879/contents.htm.

Pelsoci, Thomas M. (2010) *Retrospective Benefit-Cost Evaluation of U.S. DOE Wind Energy R&D Program: Impact of Selected Energy Technology Investments, U.S. Department of Energy*, DOE/EE-0348 (Washington, D.C.: U.S. Department of Energy.)

Ruegg, Rosalie (1996) "Risk Assessment," in Dorf, R. (editor) *The Engineering Handbook* (CRC Press, pp. 1953-1961).

Ruegg, Rosalie and Irwin Feller (2003) *A Toolkit for Evaluating Public R&D Investment Models, Methods, and Findings from ATP's First Decade* (Gaithersburg, MD: National Institute of Standards and Technology). Available at http://www.atp.nist.gov/eao/gcr03-857/contents.htm.

Ruegg, R., and P. Thomas (2011) *Linkages of DOE's Geothermal R&D to Commercial Power Generation*, DOE/EE-0382 (Washington, D.C.: U.S. Department of Energy).

Ruegg, R., and P. Thomas (2011) *Linkages of DOE's Solar Photovoltaic R&D to Commercial Renewable Power from Solar Energy*, DOE/EE-0403 (Washington, DC: U.S. Department of Energy).

Ruegg, R., and P. Thomas (2009) *Linkages from DOE's Wind Energy Program R&D to Commercial Renewable Power Generation* (Washington, DC: U.S. Department of Energy).

Saltelli, A., K. Chan, and E.M. Scott, editors. *Sensitivity Analysis* (Wiley, 2000).

U.S. Environmental Protection Agency (EPA). (2006). *User's manual for the Co-Benefits Risk Assessment (COBRA) screening model*. Developed by Abt Associates Inc.

U.S. Office of Management and Budget. (1992, 2003, 2008) OMB Circulars No. A-94, and A-4. Available at www.whitehouse.gov/omb/circulars.

Attachment 1

Drivers for Public Accountability

A number of directives and guidance memorandum from the Executive and Congress branches set impact evaluation expectations for EERE programs.

Executive Orders and OMB Memorandum:

- OMB Memorandum for the Heads of Executive Departments and Agencies, July 29, 2010 (Memo M-10-32) and Oct. 7, 2009 (Memo M-10-01) -- **increased emphasis on program evaluation in Federal Agencies.** http://www.whitehouse.gov/sites/default/files/omb/assets/memoranda_2010/m10-01.pdf

- OMB Budget Action Request (Memo 10-49), July 29, 2010 – **mandatory agency program evaluation inventory.** http://www.whitehouse.gov/omb/memoranda_default

- OMB and White House Office of S&T Policy Memorandum for the Heads of Executive Departments and Agencies on Science and Technology Priorities for the FY 2011 Budget, August 2009; **calls for R&D agencies to conduct evaluations and strengthen capacity.** http://www.whitehouse.gov/briefing-room/presidential-actions/presidential-memoranda

- OMB Performance Rating Assessment Tool (PART), 2003-2008; **set expectations for periodic systematic evaluations to be used to demonstrate results.** http://www.whitehouse.gov/omb/memoranda_m03-06/

- ARRA **unprecedented requirements for transparency & accountability**, 2009. http://www.recovery.gov/About/Documents/InitialRecoveryActImplementingGuidance_Feb18.pdf

- Executive Order 13450: Improving Government Program Performance, November 2007; **agencies shall spend taxpayers' dollars efficiently & effectively.** http://www.whitehouse.gov/sites/default/files/omb/assets/performance_pdfs/eo13450.pdf

Congress:

- GPRA Modernization Act of 2010 – **each agency shall make available on its public website an update on its performance. Agency strategic plans must include "…a description of the program evaluations used in establishing or revising general goals and objectives," and Agency performance reporting has to " include the summary**

findings of those program evaluations completed during the period covered by the update." http://www.gpo.gov/fdsys/pkg/BILLS-111hr2142enr/pdf/BILLS-111hr2142enr.pdf

- House Committee Reports HEWD, 2008/2009/2010, **calls for reporting on return on investment.** http://www.google.com/url?sa=t&source=web&cd=7&ved=0CEgQFjAG&url=http%3A%2F%2Fscience.energy.gov%2F~%2Fmedia%2Fbudget%2Fpdf%2Fsc-congressional-appropriations%2FFy-2012%2FHouse-bill%2FHEWD-FY12-Committee-Report---Final_SC_Only.pdf&rct=j&q=house%20committee%20reports%20hewd&ei=tLJnTr3VIcj50gGHipDKCw&usg=AFQjCNHDI8M3zhyIR3C7rQZrcdAbjDDd5A&cad=rja

- Department of Energy Organization Act of 1977 (42 USC 5815(b)) – **grants administrative authority for agencies to conduct program evaluations.** http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+42USC5815

Attachment 2

Guiding Principles for Evaluators

The following is a summary of highlights of the American Evaluation Association (AEA) guiding principles that bear on expected conduct of evaluators in performing the EERE benefit-cost studies:

1. Systematic Inquiry: Evaluators conduct systematic, data-based inquiries.

   This principle requires that evaluators adhere to the highest technical standards appropriate to the methods they use; that they explore with the client the strengths and weaknesses of various evaluation questions and approaches; and that they communicate their methods and approaches accurately and in sufficient detail to allow others to understand, interpret and critique the results.

2. Competence: Evaluators provide competent performance to stakeholders

   This principle requires that the evaluation team has the education, abilities, skills, and experience to carry out the proposed evaluation tasks.

3. Integrity/Honesty: Evaluators display honesty and integrity in their own behavior, and attempt to ensure the honesty and integrity of the entire evaluation process.

   This principle requires evaluators to avoid conflict of interest and the appearance of a conflict; that evaluators not misrepresent their procedures, data, or findings; and that they should attempt to prevent or correct misuse of their work by others.

4. Respect for People: Evaluators respect the security, dignity and self-worth of respondents, program participants, clients, and other evaluation stakeholders.

   This principle requires that evaluators seek a comprehensive understanding of the important contextual elements of the evaluation; that they obtain informed consent from those participating and inform participants of limits of confidentiality; and that evaluators should conduct the evaluation and communicate its results in a way that avoids unnecessarily negatively affecting the interests of stakeholders while not compromising the integrity of the evaluation findings.

5. Responsibilities for General and Public Welfare: Evaluators articulate and take into account the diversity of general and public interests and values that may be related to the evaluation.

> This principle requires that evaluators should consider not only the immediate outcomes but also broader assumptions, implications and potential side effects; that they should present results clearly and simply so that clients and other stakeholders can easily understand the evaluation process and results; and evaluators have obligations that encompass the public interest.

In summary, Principal Investigators are asked to support their benefit-cost analysis by collecting as many lines of evidence from independent sources as possible within practical constraints of data availability, time, and resources, and to use transparency in discussions of data collection, calculations, and analysis.

Attachment 3

Comparison of the EERE Approach with the 2001 NRC Approach

Summary:

For those who wish to know how the EERE approach modified an earlier NRC approach, a brief overview is provided here.

Figure A3-1 summarizes a comparison of features of the EERE and 2001 NRC approaches.. The upper left shows the original 2001 NRC framework, and the lower right shows the EERE modified framework as the yellow highlighted portion of the table, emphasizing EERE's greater focus on retrospective benefits and costs than the NRC approach.

Figure A3-1. Modified NRC Framework[25] Only Retrospective Benefits are Included

Original NRC Framework

	Realized	Options Value	Knowledge
Economic			
Environmental			
Security			

Source: Energy Research at DOE: Was It Worth It?, NRC, 2001

Modified Framework

Degree of uncertainty →

Ultimate outcomes ↕

	Realized (Retrospective)	Expected (Prospective)	Option Value
Economic[1]			
Environmental			
Security			
Knowledge			

1/ Includes energy benefits in the calculation

Source: EERE Benefits Analysis Workshop, 2004

Table A3-1 summarizes the comparison of 2001 NRC Approach to EREE modifications. In the first column are main features of the approach of the 2001 NRC Study; in the

[25] Source: Benefits Workshop, 2002

second are main features of the EERE approach. Features are aligned to allow the reader to see the modifications.

Table A3-1: Comparison of 2001 NRC Approach to EERE Modifications

NRC Study, 2001	EERE Modifications
SCOPE	
• Selected technology mix, winners & losers	• Detailed benefit-cost analysis of several technologies where economic and other benefits from a program cluster is compared against the entire program or cluster investment cost
• Technologies selected from the early 1970's to 2000 period	• Technologies selected from the early 1970's to 2008 period
BENEFITS INCLUDED	
• Benefits resulting from all capital stock installed through the present plus 5 years (in that case 2005) calculated over the entire future life-cycle of all these installations	• Economic benefits resulting from all capital stock installed up to the cutoff year. Future life-cycle benefits are excluded.
• It is to be determined if the NRC study included projected impacts for technologies not yet commercialized	• 'Realized' outcomes counted only for technologies that are already in the market, as indicated above
• Knowledge treated as qualitative catch-all for situations of technology failure in development or/and in deployment, plus descriptive listing of what were considered major technical accomplishments	• Assessment of knowledge creation and dissemination will not be limited to cases of failure. Rather identifying knowledge creation and dissemination will encompass both successful and unsuccessful technologies, within and outside the target industries. Historical tracing will identify paths and extent of knowledge flow, as well as recipients of the knowledge
• Environmental benefits - NOx, SO_2, and Carbon. Proxy values for the mitigation/ damage costs	• Avoided NOx, SO_2, PM, CO_2 equivalents. Avoided adverse health incidences associated with air emissions. Health care costs valued in dollars using EPA CPBRA model. Dollar value of CO_2 is excluded.

NRC Study, 2001	EERE Modifications
• Security benefits – Oil and LPG (Q); Electricity reliability (Y/N); Valued using $3-20/barrel based on the probability and potential impact of oil disruptions; no valuation of infrastructure threat avoidance beyond yes/no/don't know.	• Security benefits for oil and natural gas in physical units and BOE equivalent. Qualitative treatment of energy benefits.
• Work productivity, exports addressed qualitatively	• Value of increase in work productivity and exports addressed qualitatively
• Macroeconomic effects (e.g., job creation) not considered; Regional shifts not considered; Rebound effect not considered	• Job impacts excluded. Regional shifts not considered; Rebound effect not considered
• Options value addressed qualitatively	• Options value not applicable because only commercialized technologies are selected
RULES ABOUT CALCULATIONS, ATTRIBUTION	
• Next best technology is conventional technology	• Next best technology could be conventional, best available, or earlier generation of subject technology - determined on case by case basis
• 5 year rule-of-thumb to apportion credit for impact to Govt. vs. private R&D. 5 year rule assumes anything the public sector does would have been done by the private sector anyway without the Govt. within 5 years.	• Additionality analyzed on a case-by-case basis; not using a rule of thumb
It is to be clarified whether benefits/costs for lifetime of installations were cut off at 2005, or whether as stated on p. 88 of the 2001 report, benefits were calculated for the entire lifetime of installations—including lifetimes of all the installations up to 2000 and also all the installation up to 2005—i.e., a 5 year cut-off appears to have applied to the installations included—but not to the assumed	• Prospective benefits are excluded

NRC Study, 2001	EERE Modifications
lifetimes of those installations. However, there is disagreement about the approach that needs to be clarified.	
• No distinction in attribution of Govt. R&D vs. other factors driving market success of innovation	• Addresses various aspects of attribution (Govt. R&D vs. private sector; other market drivers—e.g., Production Tax Credits, etc.); ; use of an attribution matrix framework
• Partitioning attribution—NRC study not able to apply a satisfactory approach	• Use of the concept of "additionality", which describes what the gov't. R&D added that would not have occurred otherwise. Other qualitative, logical arguments will be provided in support of additionality findings.
• Levels of influence of R&D vs. standards/deployment activities not attempted	• Qualitative discussion will address the levels of influence of the R&D vs. standards/deployment activities
• No consideration of international effects	• Flows of technologies between countries and benefits of this will be recognized, as well as benefits of developing technologies within U.S.
• No discounting	• Discounting, using the current OMB guidance for public benefit-cost analysis
• Deflators -- all values in constant 1999 dollars, adjusted using GDP deflators	• All values will be appropriately adjusted to constant dollars as of the end of study's cutoff year, taking into account the discounting approach used. (Because the discount rate is a real rate, GDP price deflators are applied prior to discounting.)