U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Evaluating Realized Impacts of DOE/EERE R&D Programs

Standard Impact Evaluation Method

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PART I. Introduction, Background, and Overview

I.1 Introduction

This document (referred to as the "Guide") provides guidance for evaluators who conduct impact assessments of research and development (R&D) programs for the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE). It is also targeted at EERE program staff responsible for initiating and managing commissioned impact studies. The Guide specifies how to estimate economic benefits and costs, energy saved and installed or generated, environmental impacts, energy security impacts, and knowledge impacts of R&D investments in advanced energy technologies.

The Guide helps EERE satisfy major directives for evaluation issued by the U.S. Office of Management and Budget (OMB) and by the U.S. Congress (see Attachment 1). The impact evaluation method covered in this Guide is intended to address the following questions of interest to EERE and its stakeholders:

1. What has been EERE's economic return on investment (ROI)[1] in energy R&D?
2. To what extent has EERE's investment produced energy and environmental benefits and enhanced energy security?
3. To what extent has EERE added to knowledge 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. Has the public investment been worth it?
6. Which R&D strategies, research environment, and other factors led to a robust return on public investment and which did not, and what lessons learned can be applied to future R&D investments?

Why Perform Impact Evaluation of Federal R&D Programs?

Impact evaluation of R&D programs is motivated by the desire of program directors to manage their R&D portfolios strategically, efficiently, and effectively so as to make the best use of public investments by the American people. Systematic retrospective evaluation informs directors about possible ways to improve their programs and to position programs for the future by revealing strengths and weaknesses in past performance. It also informs stakeholders of returns from the investment.

Consistent with this aim are a host of Government directives for evaluation of Federal programs. These directives emphasize accountability, transparency, strengthened capacity, and use of results for evidence-based decision making.

Additionally, a federal energy R&D program that has determined its net impacts and return on investment is better positioned to communicate its value to its agency leadership, Congress, stakeholders, and the public than one that lacks documented credible evidence

The logic of how EERE achieves its mission is illustrated in Figure I.1. The high-level diagram of EERE logic in the figure shows how EERE's resources, activities, and

[1] In this Guide, the term "Return on Investment" (ROI) is used informally in a broad sense to refer to returns resulting from EERE investment. This is in keeping with popular usage by program directors.

outputs lead to interim and ultimate outcomes/impacts. From the resources provided by taxpayer dollars EERE assesses costs to society of the current energy system and develops programs to achieve cost reductions and other benefits. These activities create research knowledge and engineering solutions using public-private partnerships, and validate and accelerate development of advanced technologies/practices. This in turn results in commercialized technologies/ products, diffusion of knowledge, accelerated market development and uptake of new technologies. This leads to reduced energy use, cleaner energy supply, reduced air emissions, reduced oil imports, growth in market share of advanced energy technologies, and growth in the economy. Many of the outcome/impacts shown in Figure I-1 are measured by applying the methods in this Guide. Table I.1 lists the specific impact metrics that result from applying this Guide.

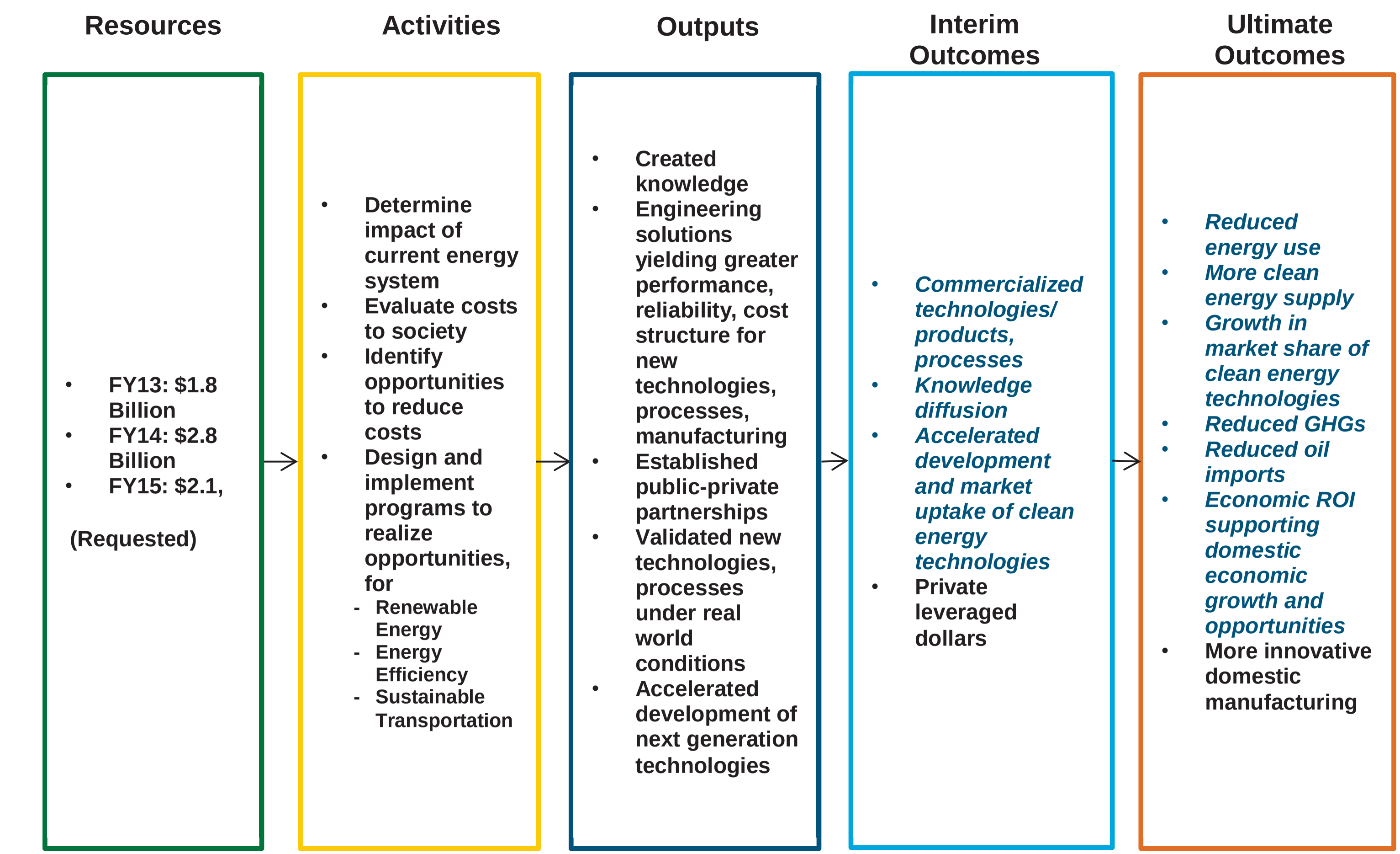
In addition to economic performance metrics, the Guide provides measures of changes in energy used and installed or generated, reductions in air emissions and related health mortality and morbidity, energy security, and knowledge creation and diffusion. All outcomes/impacts reported in Table I.1 are based on the share that can be reasonably attributed to the EERE investment rather than to other causes.[2] This new edition of the Guide—revised and extended from a previous 2011 version—reflects experience and insights gained through application of methods from previous editions in five studies completed from 2010 through 2013. In addition, meetings were held in 2012 and 2013 to solicit feedback from evaluators who conducted previous EERE benefit-cost analyses and workshops were held with EERE program analysts to get their ideas for changes.

Improvements in this edition of the Guide include the following:

- Increased standardization of approach to enhance consistency among studies;[3]
- Expansion of impact metrics, including monetization of reduced greenhouse gas (GHG) emissions;
- Improved documentation of data, assumptions, and computations;
- Increased rigor in assessing the share of impacts resulting from EERE investment;
- Additional guidance for deciding when to do a R&D ROI impact assessment; and
- Formative analysis (see Section 1.2.2) to provide insights into factors that led to (or not led to) ROI that may inform future R&D decisions for similar investments.

[2] While policy makers and program directors may be interested in additional impacts such as distributional effects, the focus of this Guide is on assessing the impacts that together determine benefits and costs and return on investment. This focus reflects intensifying federal budgetary pressures and is responsive to federal directives on evaluation.

[3] Increasing standardization of approach is intended to increase consistency among studies. It is not intended to inhibit innovation or impede improvements in approach, or to cause EERE to become out of step with OMB if it modifies its directives. To avoid such undesirable side effects, the Guide recognizes the creative role of the evaluator in confronting unique conditions of a study and in designing and implementing a suitable evaluative analysis. Further, EERE will continue to solicit feedback from evaluators and program directors on ways to further improve the Guide, and EERE will update the Guide as necessary to maintain consistency with executive and congressional directives.



Note: The outcomes in blue lettering in italics can be calculated using the standard method outlined in this Guide.

Figure I.1 High Level Diagram of EERE Logic

Table I.1 EERE Impact Evaluation Metrics Covered in this Guide

Outcomes/Impacts	Units	Definitions
Overall Economic Performance Resulting from EERE's Investments		
Portfolio Investment Cost (undiscounted)	Dollars - undiscounted	DOE/EERE total research portfolio investment (the portfolio budget over the performance period covered in the evaluation).
Gross economic benefits (GB)	Dollars - undiscounted	A simple summation of all impacts measured in dollars (undiscounted) generated by the successful market adoption of EERE-supported technologies, products, or processes.
Net economic benefits (NB)	Dollars - undiscounted	Gross economic benefits (undiscounted) less EERE investment costs (undiscounted).
Net present value (NPV) at 3% and 7% discount rates	Dollars - discounted	Present value (PV) of an investment's positive cash flow, less any negative cash flow, and less the present value of the total EERE investment cost, where discounting is performed at both 3% and 7% real discount rates.
Benefit-to-cost ratio (BCR) at 3% and 7%	Ratio	A ratio formed by setting the numerator as the present value summation of monetized benefits resulting from EERE's investments, and the denominator as the present value of EERE investment costs, where discounting is performed at both 3% and 7% real discount rates.
Social return on public investment (measured using the Internal rate of return (IRR)	Percent	The percentage yield on an investment found as the solution interest rate that, when used in appropriate discount formulas, equates social benefits resulting from EERE's investments with EERE's investment costs, resulting in a Net present value (NPV) of zero. The IRR can be compared with the OMB-specified real discount rate, currently set at 7% for benefit-cost analysis.
Monetary Value of Energy and Other Resource Impacts and of Environmental Impacts Resulting from EERE's Investments		
Monetary value of energy and other resource impacts	Dollars – discounted	Year-by-year and total monetary value of energy saved or installed or generated, and of labor and other resource impacts, undiscounted and discounted at both 3% and 7% real discount rates.
Monetary value of greenhouse gas emissions reduction	Dollars – discounted	Year-by-year and total monetary value of avoided cost of carbon dioxide (and equivalents) emissions, using the social cost of carbon (3% discount rate values).
Monetary value of avoided adverse health incidence due to reduced air emissions	Dollars – discounted	Year-by-year and total monetary value of avoided adverse health events due to air emissions, discounted, at both 3% and 7% real discount rates.
Energy and Other Resource Impacts, in Physical Units, Resulting from EERE's Investments		
Energy saved	Btu, type of fuel saved	The quantified amount of energy savings resulting from an EERE energy-efficient technology, product, or process.
Installed renewable capacity	MW	The quantified amount of renewable energy capacity increase attributable to an EERE investment in renewable energy.
Renewable Generation	kWh	The quantifiable amount of increased renewable energy generated attributable to an EERE investment in renewable energy.
Non-fossil fuel volume produced	Gallons	The quantifiable amount of non-fossil fuel (e.g., bio-diesel and ethanol (e.g., E85) for transportation) produced by an EERE-funded process or technology.

(Continued)

Other Resource Impacts (e.g., Changes in land resource use, labor, or materials)	Relevant units	Descriptions of changes in land resource use, labor, or materials
Environmental Impacts in Physical Units Resulting from EERE's Investments		
Avoided Air Emissions		
Avoided greenhouse gas emissions in CO_2e (carbon dioxide emissions (CO_2) or equivalents – e.g., methane (CH_4), and nitrous oxide (N_2O))	Metric tons ($MMTCO_2e$)	Year-by-year and total amount of avoided greenhouse gas emissions from advancements in clean energy technologies enabled by EERE investment.
Avoided sulfur dioxide emissions (SO_2)	Short tons	Year-by-year and total amount of avoided sulfur dioxide emissions accrued from advancements in energy technologies enabled by EERE investment.
Avoided nitrogen oxides (NOx)	Short tons	Year-by-year and total amount of avoided nitrogen oxide emissions accrued from advancements in clean energy technologies enabled by EERE investment.
Avoided particulate matter emissions ≤ 2.5 micrometers ($PM_{2.5}$)	Short tons	Year-by-year and total amount of avoided $PM_{2.5}$ emissions accrued from advancements in energy technologies enabled by EERE investment.
Additional emissions, including carbon monoxide (CO), volatile organic compounds (VOC), and ammonia (NH_3)	Short tons	Year-by-year and total amount of these additional avoided emissions accrued from advancements in energy technologies enabled by EERE investment.
Other Types of Environmental Emissions		
Changes in water consumptions and discharges; and solid waste generation	Relevant units	Descriptions of changes in water or waste generation
Health Impacts in Physical Units		
Reduced morbidity (e.g., avoided respiratory symptoms, chronic bronchitis, nonfatal heart attacks) and mortality	Number of incidents, episodes, cases	Year-by-year and total avoided adverse health incidence due to reduction in air emissions resulting from advances in energy efficiency and renewable energy technologies sponsored by EERE.
Energy Security Impacts Resulting from EERE's Investments		
Displaced petroleum consumption	Imported oil measured in gallons of gasoline equivalent, or barrels of oil	Year-by-year and total imported oil displacement associated with EERE-attributed technologies, products, or processes.
Reduced vulnerability of U.S. energy infrastructure	Qualitative	Descriptions of changes in potential vulnerability of the energy infrastructure to damage or other disruptions.
Knowledge Created and Disseminated Resulting from EERE's Investments		
EERE-attributed patents issued	Number of patents	Identification of EERE-attributed patents by date, patent number, assignee, and title.

(Continued)

Patent citations	Citation rates - forward and backward linkages, citation index values*, and identification of notable patents	Frequency with which other organizations reference earlier EERE-attributed patents indicating in the case of backward linkages to major innovators in the target industry their potential influence on commercialization; in the case of forward linkages their potential influence both inside and outside the target industry; and in the case of high citation rates the identification of particularly influential patents.
DOE patent citation rank among organizations in the field	Rank	DOE rank among organizations in terms of having its patents in the target industry cited by later patents of others in the field
Optional Knowledge Measures		
Knowledge spillovers	Linkages to other technologies, industries, and organizations outside the targeted areas	The frequency with which EERE-attributed patents influence technology areas and organizations beyond the original area or industry of focus.
EERE-attributed publications	Number of publications	Identification of EERE related publications by date, sponsoring organization, author, and title
EERE publications most cited by other publications	Listing	EERE publications most cited by other publications
Publication citations by patents	Citation rates of publications by patents	The frequency with which patents reference EERE publications, indicating those publications that are particularly important to innovation.
Technology Acceleration (as applicable) Resulting from EERE's Investments		
Technology acceleration	Number of years that technology development and commercialization are accelerated.	The extent to which an EERE investment facilitates the accelerated achievement of a technical advance and its commercialization.

Note: Several measures within and across categories of impact are different facets of the same impact, such as mortality and morbidity incidence and the economic value of avoided incidence, and energy saved in physical units and energy saved in dollars. These overlapping values occur in the process of providing intermediate values that are of interest particularly to EERE program directors. Double counting would result from summing across all individual impacts (if they were expressed in commensurate terms). However, there is no double counting in the economic performance measures.
***** The Citation Index adjusts for the type of technology and for the age of the patent, such that, for example, the Index value of 5.0 means that a patent has been cited approximately 5 times more often than would be expected of a patent of its age, within its technology area.

The method presented in this Guide builds not only on the preceding edition of the Guide, but also on previous efforts by others. It adopts a portfolio assessment approach pioneered by the Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST) and significantly improves the approach employed by the National Research Council (NRC) in the 2001 study, *Energy Research at DOE: Was It worth It?* It builds on work of the U.S. Environmental Protection Agency (EPA) to extend the evaluation to encompass environmental impacts. It draws on earlier technology characterizations and approaches to research evaluation performed under the direction of NIST, along with the growing body of evaluation literature in science and technology.[4]

Special features of the EERE impact evaluation methodology presented in this Guide include:

- Criteria for deciding when to perform R&D impact evaluation using the Guide;
- A portfolio approach that offers a cost-effective means of estimating a lower-bound return on a relatively large group of R&D investments;
- Characterization of technologies by type and related characterization of the next-best alternative;
- Five economic performance measures: undiscounted benefits, undiscounted net benefits, net present value (NPV), benefit-to-cost-ratio (BCR), and internal rate of return (IRR) on investment, where discounting is performed for multiple rates;
- Economic performance measures computed at three levels of analysis that reflect differences in degrees of certainty in results. This includes, first, dollar value of resource impacts (most certain); second, dollar value of resource impacts plus value of environmental health impacts; and, third, all of the above monetary values plus dollar value of GHG impacts (least certain);
- Multiple categories of impacts – energy, labor, and other resource impacts, environmental impacts, energy security impacts, and knowledge creation and diffusion;
- Monetary and physical valuations of energy and other resource impacts;
- Monetary and physical valuations of environmental impacts including reductions in CO_2 and other air emissions, and health-related changes;
- Energy security impacts in physical and in qualitative terms;
- Knowledge creation and diffusion impacts;
- A primary focus on retrospective, empirically based benefits and costs;
- Extension of benefits to show impact of taking account of remaining effective useful life (EUL)[5] of an installed systems;
- Provision of conservative, lower-bound estimates subjected to sensitivity analysis; and
- Analysis to identify R&D strategy, research environment, and other factors conducive (or not conducive) to realizing a robust ROI.

The Guide is organized in two main parts:

PART I introduces the Guide in Section I.1. Section I.2 explains underlying concepts and terminology. Section I.3 explains when it makes sense to launch an impact evaluation study. Section I.4 gives an overview of the 14 steps for conducting an R&D ROI evaluation. Section I.5 highlights the roles and responsibilities of EERE staff and of independent evaluators, respectively, in conducting evaluations using the Guide.

PART II leads EERE program staff and evaluators step-by-step through the process of conducting an evaluation of the social return on EERE's R&D investments. It

[4] Particularly helpful were earlier guides and handbooks on benefit-cost analysis and other aspects of evaluation of public science and technology programs, such as those by Tassey (2003), Ruegg and Feller (2003), Powell (2006), Link and Scott (2011a), Link and Scott (2011b), and Link and Vornotas (2013 ed.)

[5] Effective useful life (EUL) is the period over which an asset, such as plant, equipment, and systems and components, with normal maintenance and repair, can be expected to continue to be usable for the intended purpose.

emphasizes the use of common criteria and consistent approaches across studies and provides examples drawn from previous studies.

I.2 Key Concepts and Terminology

I.2.1 Retrospective Evaluation versus Prospective Analysis

This Guide primarily has a retrospective focus. The Guide's retrospective approach to evaluation means that it estimates impacts based on what has actually happened. This approach may be contrasted to a prospective evaluation approach that estimates what potentially may happen, but only if stated assumptions hold.

Although the analysis defined in this Guide has a retrospective focus, it also includes a separate, extended analysis that takes into account the remaining Effective Useful Life (EUL) of products/processes put in place during the retrospective study period. The rationale for taking account of remaining EUL is that the public policy decision and resulting program investment have been made, and the customer has already made the decision to adopt the subject energy-related product/process, thus removing much uncertainty. However, to preserve the retrospective focus, the remaining EUL analysis results are reported separately.

I.2.2 Formative versus Summative Evaluation

Formative evaluation examines the program management process and looks for ways to improve it; thus, it is usually emphasized relatively early during an investment when there is still time to make adjustments.[6] In contrast, summative evaluation estimates outcomes and impacts and assesses the overall worth of an investment.

Because of the Guide's focus on retrospective evaluation, it features summative evaluation, (i.e., measuring the realized return on EERE's investment). However, it also features elements of formative evaluation—not in the conventional sense of real-time or near-term process evaluation, but rather in the sense of providing an assessment of EERE's program strategies and identifying which among those examined have proven particularly successful in contributing to return on investment. Along with this formative assessment, the evaluator is asked to provide actionable recommendations where possible. The objective is to provide feedback that informs future similar investments.

I.2.3 Portfolio Approach to Impact Evaluation

The impact evaluation approach supported by this Guide is designed for application to a portfolio of projects or technologies rather than to a single project or single technology. A portfolio may be defined as an entire program, a subprogram, a group of programs, or other grouping of projects or technologies or activities.[7]

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[6] EERE has also supported development of an evaluation framework that guides retrospective evaluations in the early-to-intermediate term of an EERE investment. It features progress metrics and formative analysis, particularly of supply chain development, but also includes measurement of intermediate outcomes where they can be measured. See Jordan, Mote, Ruegg, Choi, and Becker-Dippmann (2014).

[7] Users of previous editions of the Guide are alerted to a change in terms. Previously, "cluster" was used to designate the larger portfolio under study. However, this usage proved confusing to users. The point of confusion was whether “cluster” referred to the portfolio (which it did) or to the subset of projects selected from the portfolio for detailed analysis (which it did not). To avoid this confusion, “portfolio” replaces “cluster” in this 2014 edition of the Guide.

The portfolio approach calls for first defining the portfolio and then selecting individual projects/technologies from the defined portfolio for detailed evaluation of their positive and negative impacts. The impacts of the remaining projects/technologies within the portfolio that are not selected for detailed analysis are treated qualitatively; they are not ignored. Investment cost is defined as the total EERE investment cost for the entire portfolio. Thus, investment costs include both the projects/technologies that are evaluated in detail and those that are not.

The portfolio approach offers a cost-effective alternative to the need to evaluate the return on R&D investments. It does this by focusing the quantitative analysis on a few projects/ technologies within a larger portfolio, while allowing broader conclusions to be drawn about the entire portfolio. In this way, it saves in evaluation costs by reducing the number of projects that must be evaluated in detail in order to draw conclusions about the portfolio overall. The ability to focus on only a few projects relies on the fact that a relatively small share of projects in many high-risk R&D portfolios account for most of the benefits.[8]

When it makes sense to hand-select the projects/technologies for detailed analysis rather than to draw them randomly, the selection should focus on projects that have experienced both technical and commercial success. This project selection criterion is in keeping with the objective of an efficient approach to determining if a portfolio investment has been economically worthwhile based on a lower-bound estimate.

It should be noted that if program directors wish to apply other criteria for selecting projects for detailed assessment (such as to examine a range of performers or projects that have failed) they should recognize that use of these other selection criteria may serve a different evaluation objective than that served by the Guide.[9]

Impacts[10] of the group of selected projects/technologies are compared against the total portfolio investment cost. The result is a lower-bound estimate of return, because not all of the portfolio benefits are

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[8] Policy makers and program directors funding high-risk R&D, like venture capitalists, generally have to choose an array of projects in order to find the few that will turn out to be highly successful. When a few projects account for most of the returns, a randomly drawn sample of projects will not provide a fair test of whether the portfolio investment has been worthwhile because the sample, unless extremely large, will tend to contain all or a high proportion of less commercially successful projects and miss the successful projects. In the case that the evaluator confronts a portfolio comprised of projects all with modest gains, drawing a relatively large random sample of projects for detailed evaluation is a reasonable selection approach. In this case, the economies of the portfolio approach described here will likely be reduced, but other aspects of the approach should still apply. On the other hand, if the evaluator confronts a portfolio comprised mostly of commercial successes, either a random selection process or a focused selection could be used to select projects for detailed analysis. Based on experience, however, it is expected that the more typical distribution of R&D projects will be one where a few projects account for a disproportionate share of portfolio benefits.

[9] If a program director wishes to extend the benefit-cost analysis to include detailed assessment of a limited number of projects that have been commercial failures—such as to better inform the formative part of the analysis or to assess in more detail the effects of "failed projects"—a fair test of portfolio performance requires that the commercial failures be in addition to the projects/ technologies selected because of their commercial success. If the program director wishes to look only at commercially failed projects perhaps he/she actually wishes to conduct a different type of study than that covered by this Guide, (e.g., a "failure analysis" rather than a "benefit-cost analysis" or "impact analysis").

[10] This edition of the Guide emphasizes use of the term "impacts" in place of "benefits" to provide a more neutral term that does not presuppose a positive result. However, once positive and negative impacts have been combined and are being compared against investment costs to compute economic performance measures, the terms "benefits and costs" are used.

quantified, while all of the costs are quantified.

Therefore, the question of whether the portfolio investment has been worthwhile rests on evidence provided by a lower-bound estimate of economic returns. The unit of analysis remains the portfolio, despite the use of a selection of projects/ technologies on which to measure benefits of the portfolio.[11] If the projects/ technologies selected for detailed analysis have generated sufficient economic benefits to cover or exceed total portfolio investment cost and, in addition, there is no evidence that the remaining projects/ technologies have produced negative impacts offsetting those benefits, this finding can be taken as evidence that the portfolio investment has been economically worthwhile.

It is possible to expand the selection of projects/technologies for detailed analysis in subsequent evaluations. Likewise, subsequent evaluations may allow additional time for market development for currently immature technologies. Thus, the lower-bound estimate of return could be raised by subsequent evaluations of a given portfolio.

Figure I.2 illustrates the elements of the Guide's portfolio approach. The bracketed green rectangles together represent the portfolio under study and its impacts. The darker green rectangle represents the individual technologies selected from the portfolio for detailed impact assessment. The lighter green rectangle represents other technologies in the portfolio that are not selected for detailed study but rather are treated qualitatively. Qualitative analysis of this group of remaining technologies in the portfolio may provide evidence that they have added to overall portfolio benefits. Conversely, the qualitative analysis may indicate if they have had potentially negative impacts that may offset positive impacts of those selected for detailed analysis. In Figure I.2 the orange box to the right represents the portfolio's entire investment cost. The portfolio cost is inclusive of costs of the individual technologies selected for detailed study that may be broken out for an additional comparison. By comparing the dollar value of benefits for the selected technologies against entire portfolio cost a lower bound estimate--a minimum rate of return--is found for EERE's investment in the portfolio.

I.2.4 Multiple Categories of Impacts

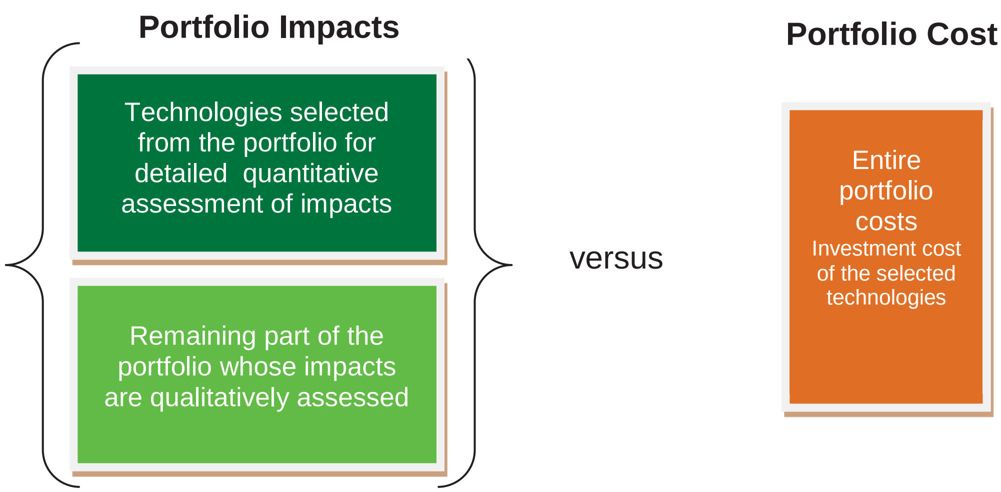
The current approach provides a more comprehensive impact treatment than previous EERE approaches by accounting for the following categories of impacts:

- **Energy and Other Resource Impacts** resulting from changes in energy, labor, capital, and other economic resources.
- **Energy Impacts** are called out for separate treatment because energy is the focus of the EERE programs. Energy is treated in terms of the physical quantity of energy saved or installed/ generated as a result of the technology evaluated.
- **Environmental Impacts** driven by changes in air emissions—including CO_2, NO_x, SO_2, $PM_{2.5}$, and other air emissions—resulting from changes in use of fossil fuels due to the subject technologies. Greenhouse gas reductions are valued in physical units and also in dollars by applying Social Cost of Carbon (SCC) estimates. Changes in other air emissions in turn drive changes

[11] This portfolio evaluation approach with its lower-bounds estimate may be contrasted with a "cherry picking" approach to evaluation that selects only successful projects and compares their benefits against their individual project investment costs and uses the results to represent the cost-effectiveness of the entire portfolio. That is not the approach used here.

in public health mortality and morbidity. Health effects are calculated using the Environmental Protection Agency's (EPA's) Co-Benefits Risk Assessment (COBRA) model. Avoided mortality and morbidity are stated in terms of incident rates, and the value of these avoided adverse health events is stated in dollars. If significant, other environmental impacts, such as water discharges, land resource use, and solid waste generation, are treated qualitatively.

- **Energy Security Impacts** are treated in part quantitatively and in part qualitatively, but not in dollars. Displaced petroleum consumption is measured both in terms of gallons of gasoline equivalent and barrels of imported oil. Notable changes in the security of energy infrastructure (such as the utility grid and storage and delivery systems for natural gas, petroleum, and other energy sources) are treated qualitatively. The evaluation approach does not monetize any energy security benefit at this time because the valuation methods are not settled.



Note: "portfolio" is entire program, subprogram, or other grouping to be studied

Source: Rosalie Ruegg, TIA Consulting

Figure I.2 Illustration of EERE's Portfolio Approach

- **Knowledge Impacts** focus on the creation and dissemination of knowledge outputs of the entire portfolio investment as indicated by patent and publication counts and citations. Knowledge impacts are not expressed in dollar terms, except in so far as knowledge advances underlie the energy, other resource, and environmental benefits that are expressed in dollars. Because knowledge provides a foundation for additional innovation, it is separately reported as a spillover impact in nonmonetary terms, but nonetheless quantitatively.

By comparing combined benefits valued in dollars against portfolio investment costs, a financial return on EERE R&D investment is obtained. Additional positive impacts are measured but not in dollars. Because they are incommensurable with the dollar valuation, they are not part of the calculated economic performance metrics. However, impacts—whether measured in dollars, in physical units, or described qualitatively—reflect, in a broad sense, evidence of the larger return on R&D investment.

In this Guide, the term "Return on Investment" (ROI), as noted previously, is used informally in a broad sense to refer to the social returns from EERE investments inclusive of economic returns measured in dollars as well as other impacts measured in other terms. It is recognized, of course, that only impacts measured in dollars are actually incorporated in percentage rate-of-return measures, but conceptually this broader use of ROI serves as a reminder of total impacts.

I.2.5 Social Return on EERE Program Investments

An objective of the impact evaluation performed according to the Guide is to provide an estimate of the social return on EERE's investment. To explain the meaning of this term, it is useful to distinguish between an evaluation performed for a company and one performed for a public program. A major difference is perspective and breadth of coverage.[12] In simplistic terms, private Company X takes into account its own cash inflows and outflows in calculating the return on its investment. Impacts of its actions on others, such as on Company B who loses revenue in the face of increased competition from X, or Company C who gains revenue by learning from Company X, are not included by Company X in the calculations of return on its investment.

In contrast, a public program typically takes into account impacts resulting from its actions within a broad sphere of interest, including, but extending beyond, private returns. That is, all resulting gains and losses of significance to the nation, regardless of who experiences them, are relevant to computing the social return on a federal program investment. Thus, a federal impact evaluation typically has a much broader perspective and scope of coverage than does a private-company analysis. For this reason, it is typically much more complex and challenging to perform than a private company analysis.

"Social return" is a term used to signify the broad inclusion of impacts to society from an investment—inclusive of both private returns and spillover returns—which together comprise social returns. Here, the qualified term *"social return on public investment"* or, more specifically, *"social return on EERE's investment"* is used to indicate inclusiveness of all social benefits on the impact side resulting from EERE's activities. This benefits perspective is contrasted with an investment-side focus on

[12] Another essential difference in a federal impact evaluation and that of a private company is the treatment of taxes. For a private company, it is important to include tax effects on company cash flows (i.e., adjust for taxable and tax-deductible items), taking into account tax credits, depreciation, tax deductions of interest payment and other business expenses, and related effects. In contrast, an impact evaluation of a federal investment program that is not directly using the tax system as a policy mechanism, such as that covered by this Guide, can generally ignore tax effects in its impact analyses. Moreover, there is a growing "public values" literature that argues for additional impacts to be taken into account in public impact evaluation, such as effects on income distribution, employment effects, and balance of payments—effects that traditionally have been omitted from benefit-cost analysis. The Guide expands coverage of benefits to include environmental, energy security, and knowledge effects, in addition to energy and other resource effects, but does not extend the coverage to income distribution effects, employment effects, or balance of payment effects. Regarding employment effects, it should be recalled that many of the investments covered retrospectively took place largely during periods that were characterized by full employment, such that they would be small in any case.

EERE's expenditures on the portfolio under evaluation. That is, investment costs refer to DOE/EERE's investment[13] rather than total societal investment costs, which would include investment not only by DOE/EERE but also by all other parties. The social rate of return on EERE's investment is computed *using the Internal Rate of Return (IRR)* method. The IRR is supplemented by other measures of economic performance described in Table I.1.

The quantitative economic performance measures, which are based on impacts measured in constant dollars, are presented in a three-level analysis. Each level adds additional benefits to be compared against EERE's portfolio investment costs:

1. Level one compares energy and other resource savings against total portfolio investment costs.
2. Level two compares the combination of energy and other resource savings and the economic value of avoided adverse health events against total portfolio investment costs.
3. Level three compares the combination of energy and other resource savings, value of avoided adverse health events, and value of reduced GHGs against total portfolio investment costs.

I.2.6 Conservative, Lower-Bound Estimates

The resulting measures of economic performance are expected to provide a conservative, lower-bound estimate of actual returns for three reasons:

1. The retrospective approach avoids reliance on forecasted data with higher degrees of uncertainty; nevertheless, benefits in most cases are expected to continue past the cut-off year of the analysis. When, in a separate, secondary analysis, remaining EUL impacts resulting from investments already made are included, it is expected that the estimates will remain conservative for the additional two reasons given below.
2. The portfolio approach includes all investment cost for the portfolio, but quantitative benefits are based on only a subset of technologies drawn from the portfolio for detailed analysis.
3. Not all impacts of the technologies selected for detailed analysis are valued in monetary terms. Impacts of avoiding environmental effects from land and water pollution, energy security impacts, and knowledge spillover impacts are among the effects that are only expressed in nonmonetary units.

I.2.7 Theoretical Foundation for Evaluation of Social Returns

This section treats in brief the theory developed largely by Zvi Griliches and Edwin Mansfield for analyzing private returns and spillovers, upon which the Guide's approach to evaluation of social returns is derived. Social returns encompass private returns plus consumer surplus (i.e., market spillovers), plus other spillover effects (e.g., knowledge spillovers and network spillovers) that may apply.[14]

Early analysis applications by Griliches and Mansfield proved useful for conceptualizing and estimating social and private returns on

[13] In most evaluations performed under the Guide, investment costs are exclusively EERE's. However, in at least one case DOE Office of Science costs also contributed to an EERE technology portfolio that was evaluated. In such case, all DOE investment costs are taken into account. To emphasize this point, DOE/EERE is used here instead of EERE alone.

[14] Mansfield's model, which is described in this section, takes into account private returns and market spillovers (called "consumer surplus" within the context of the model).

investment in new technologies.[15] Griliches applied his approach to measuring social returns on investments to develop hybrid corn. Building on Griliches' work, Mansfield applied his model to assess the social benefits of private-sector industrial innovations, and found that the estimated social rate of return for a group of selected industry innovations were generally higher than the private rate of return. Like Griliches, he concluded that there may be a substantial "spillover gap" between private and social rates of return on innovation. A public policy implication is that private investment decisions, which do not take into account spillover effects, will tend to result in less investment in R&D and innovation than is optimal from the standpoint of society at large.[16]

The seminal work by Griliches and Mansfield has long informed the analysis of federal R&D investments. Their work, which is well known to economists/practitioners of social benefit-cost and impact evaluations, continues to provide a theoretical anchor and unifying framework for such evaluation studies.[17]

The simplified representation in Figure I.3 of Mansfield's model serves to illustrate the basic concepts. Suppose that an innovation 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. Mansfield acknowledged that the calculations are not this simple, but indicated that the basic model conveys the spirit of the analysis.[18]

With reference to Figure I.3, DD' depicts a demand curve for good(s) 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 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

[15] See Z. Griliches (1958), E. Mansfield, J. Rapoport, A. Romeo, S. Wagner, and G. Beardsley (1977); Foster Associates, (1978); and Nathan Associates (1978) to learn more about the model's development and early use.

[16] This is not to say that the private rate of investment is lower than it should be based on the private risk adjusted expected rate of return relative to the private marginal cost of capital. Rather, the presence of large spillover effects not captured by private investors and, hence, not factored into their investment decisions may argue for supplementary public investment in cases where the gap between social benefits and private benefits is particularly large due to large spillover benefits.

[17] Z. Griliches (1958), and E. Mansfield, et al. (1977).

[18] 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 planning report for that effort. See Mansfield (1996).

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.3. 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.3. First, if the innovation replaces another product, the resource savings cited above does not equal the profits of the innovator.

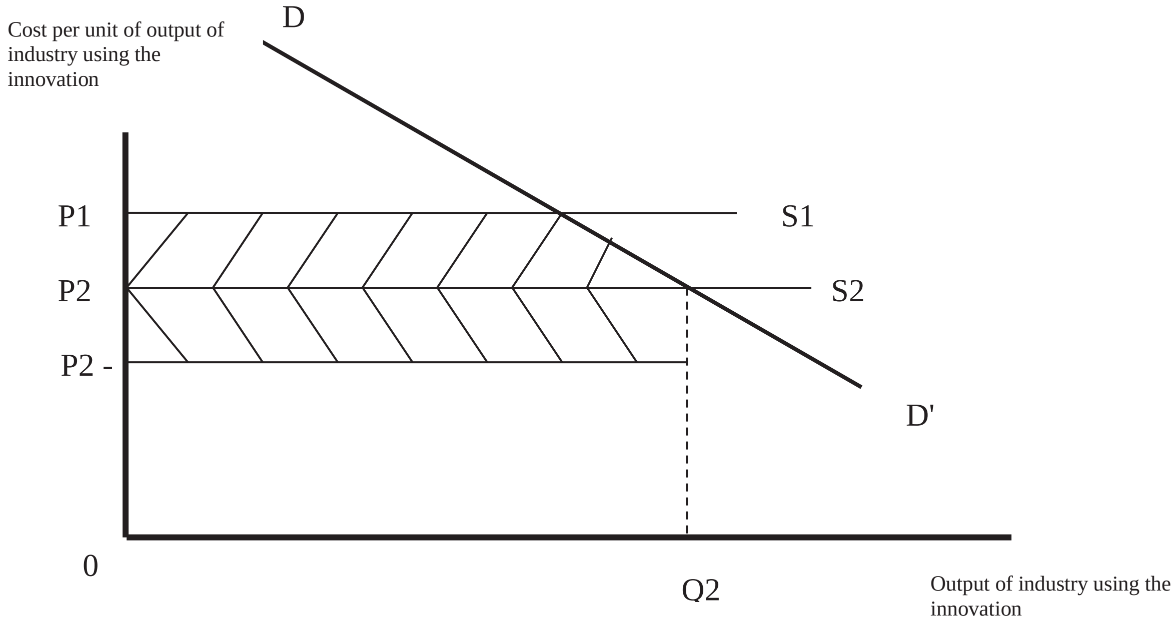
Instead, it equals these profits less those that would have been made (by the innovator and/or other firms) if the innovation had not occurred and the displaced product had been used instead. Second, if other firms imitate the innovator and begin selling the innovation to the industry that uses it, their 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.3 equals:

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

where K = (P1 - P2)/P2, and n is the price elasticity of demand (in absolute value) of the product in 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 simplification has



Source: Edwin Mansfield (1996)

Figure I.3 Mansfield Model of Social Benefits from an Innovation that Reduces the Cost of Producing a Good Sold

been helpful in the practical application of Mansfield's model. Despite simplification in the model, there is a substantial challenge in compiling the data necessary for the analysis.

Not included in the depiction of Figure I.3 are knowledge spillovers 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 in Figure I.3 are non-economic impacts, such as environmental and energy security impacts, and the more general impacts of an enhanced knowledge base on the innovative capacity of organizations.

In addition, the Mansfield approach incorporates supply side shifts only, thus ignoring possible dynamic effects that may also affect demand schedules. In fact, while EERE emphasizes R&D, which is expected to have its impact primarily on supply schedules, EERE also conducts deployment activities that are aimed at influencing demand schedules—a condition not addressed by the Mansfield model.

Areas not covered by the Mansfield approach have necessitated departure from strict adherence to the Mansfield model, primarily to account for demand-side effects and additional types of benefits. At the same time, most evaluation studies to date have focused on supply-side effects from R&D, and have conformed to the model in terms of resource-driven economic impacts. Despite the lack of perfect alignment of EERE evaluation requirements and the Mansfield model, the model continues to be considered foundational to the Guide's approach—conditioned by an understanding that modifications/extension can be made to reflect actual circumstances that do not conform strictly to the model's limiting assumptions.

I.3 Deciding When to Evaluate the Return on Investment

Impact evaluations are conducted to learn about and improve programs, determine whether they are effective, and communicate the value to stakeholders. These intended uses of impact results condition when to conduct an evaluation. This section focuses on some of the key considerations for when to evaluate EERE's return on investment.

Not every possible portfolio grouping within an R&D program need be recommended for a ROI impact evaluation. Before launching a retrospective evaluation using the Guide, the program director should consider the factors described below that influence when it makes sense. The first consideration is to determine if a portfolio area—and elements within it—have had sufficient time to progress to a state of readiness for a retrospective impact evaluation. Figure I.4 shows when it is too early to evaluate retrospectively the economic return on an emerging technology, and a point beyond which such an evaluation may be appropriate.

As the diagram shows, during the stages in a technology/product/process life cycle (i.e., when a technology is at Technology Readiness Levels (TRL) 1 through 9, or early in post-TRL 9)[19] (see Attachment 2), it has not had sufficient time to generate benefits. At an early stage, a technology may be found not yet to have been economically worthwhile, although it may be at a future time. Findings from an economic evaluation of a technology conducted prematurely may possibly not show returns because the assessment was performed too early, before the market could develop. After a technology has been commercialized and benefits have had time to accrue, then the return on investment can be evaluated. Stage of technology development/market penetration is, therefore, a make or break consideration in deciding whether to launch a R&D impact evaluation.[20] After determining if the stage of technology development/market penetration is conducive to undertaking a R&D impact evaluation, there are additional factors to consider. Table I.2 lists factors that will influence whether to proceed with an evaluation using the Guide.

Closely related to the above are considerations on the level of rigor necessary. Since R&D ROI impact evaluations typically are performed to meet one or more of the conditions such as those listed below, it is important that they be robust and defensible.

- A program/subprogram/ portfolio/ initiative is receiving a high level of external attention;

[19] TRL is a measure of technical readiness originally developed by NASA in the 1980s, and endorsed in 2001 by the Government Accountability Office (GAO) for use in new major federal programs to identify the maturity of emerging technologies. Based on a 1-9 scale, TRL 1 indicates a newly invented technology on which analysis and testing has not yet been performed, and TRL 9 indicates that the system has been proven and is ready for commercialization.

[20] There are other evaluations that may be appropriate to conduct in the early TRL stages (e.g., pre-TRL 9), such as that covered by EERE's Framework for Evaluating R&D Impacts and Supply Chain Dynamics Early in a Product/Technology Life Cycle (Jordan, et al., 2014). For an account of additional evaluation methods that are applied at different stages and for a variety of purposes, see Ruegg and Jordan (2007).

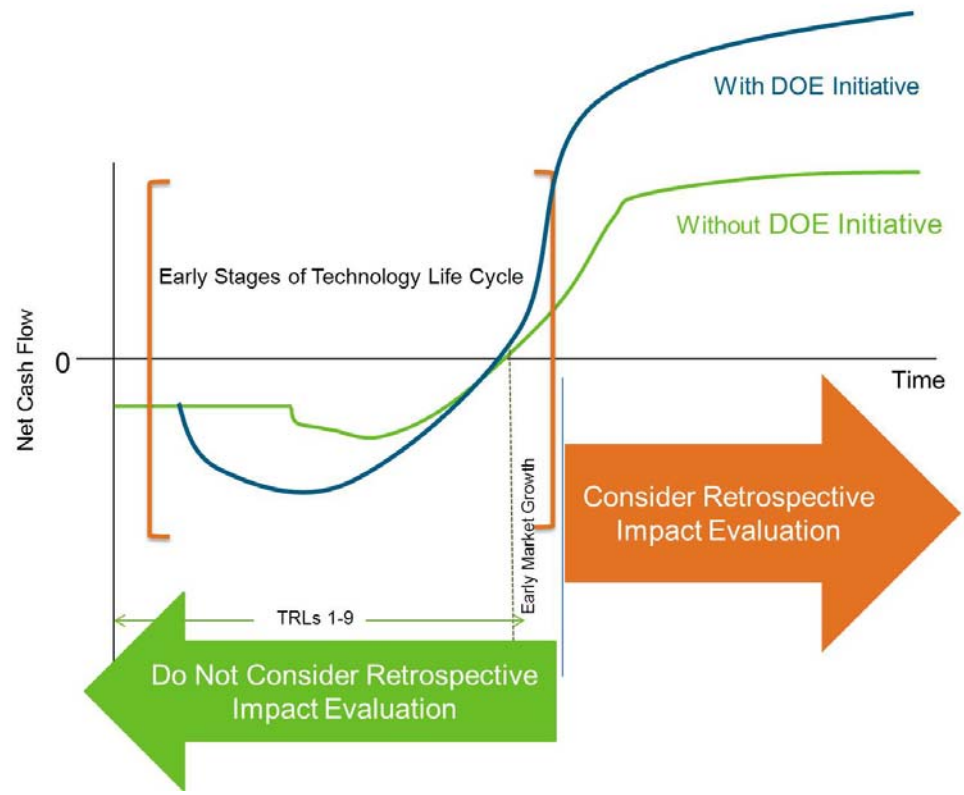


Figure I.4 When to Conduct a Retrospective Impact Evaluation of an Emerging Technology

- A program/ subprogram/ portfolio/ initiative is a White House/ Congress/ DOE Secretary/ EERE Assistant Secretary priority;
- The portfolio area is a major budgetary priority or involves a large public investment;
- The portfolio investment addresses a particularly pressing and important problem;
- The portfolio investment is of critical path importance to achieving DOE and EERE strategic goals; and
- There is interest in adopting a similar major investment strategy elsewhere, and a need to first assess its achieved impact.

Table I.2 Overview of Factors to Consider in Deciding Whether to Launch a Retrospective R&D ROI Impact Evaluation of an EERE Portfolio

Decision Criteria	Supportive of Launch of a R&D ROI Evaluation	Not Supportive of Launch
Technologies that make up the portfolio are still at an early stage of market penetration		No Go, even if other conditions are favorable, because long-term impacts cannot yet be measured.
Technologies that make up the portfolio are sufficiently past the early market stage as to have achieved market growth	Go if one or more of the other conditions are favorable	
• For the portfolio, there is direct evidence, or a perception, of substantial market penetration in at least some areas.	X	
• For the portfolio, sufficient time has passed for market effects to be observed (e.g., at least 3 years) in at least some areas, but not too far in the past to make data collection infeasible.	X	
• The portfolio includes one or more technologies with realized benefits, though the ROI is unknown.	X	
• Selected technologies from the portfolio, or the portfolio overall, were previously evaluated but had not shown notable realized economic ROI, in part due to insufficient passing of time.	X	
• Selected technologies from the portfolio, or the portfolio overall, were previously evaluated more than 5 years ago and an updated assessment is required.	X	
• Congress directs a study be done for the portfolio.	X	
• The portfolio of interest has recently received a retrospective impact evaluation.		X
• The portfolio of interest largely overlaps previous portfolios that have received a retrospective impact evaluation.		X
• The portfolio area has lower priority than other areas based on stakeholder interest.		X

I.4 Overview of the 14-Step Evaluation Approach

An overview of the step-by-step process of conducting an R&D ROI impact evaluation for EERE is given in Figure I.5. Depicting the evaluation approach as a series of sequential steps in Figure I.5, as well as in Part II of the Guide, is intended to foster a common approach across studies, increasing the amount of "science" that goes into each EERE impact study. Studies done according to the Guide are not intended as "free-form" stand-alone entities; rather they comprise a series of related studies that together measure EERE's impact over time.

As discussed in the next section, most of the steps listed in Figure I.5 are the responsibility of the evaluator. However, EERE staff have responsibilities throughout, particularly in Steps 1, 13, and 14.

I.5 Roles and Responsibilities of Independent Evaluators and of EERE Evaluation Project Managers

Both the evaluation project manager and the independent evaluator have critical roles and responsibilities in applying the standards set in this Guide to R&D evaluation. EERE program directors have, first, to decide if they will recommend that a given R&D portfolio be evaluated. If the decision is to proceed, the evaluation project manager has to obtain an evaluator using a competitive solicitation process. Then he/she will be expected to collaborate with the evaluator to verify the definition of the portfolio, select projects/technologies from the portfolio, and assist the evaluator to obtain portfolio investment costs, project contacts (e.g., principal investigators, technology developers), and other data. He/she will be responsible for ensuring peer review of the draft study plan and organizing others—both independent external experts and internal DOE experts—to participate in the review The involvement of the evaluation project manager is expected to increase again as the study nears completion, and the draft report is peer reviewed, the final report is published, and its results are used by the program office.

Independent evaluators are chiefly responsible for successfully conducting an EERE evaluation study in compliance with the standards and specifications set forth in the Guide. Early steps toward that success include working with EERE staff to scope and plan the study and to make revisions and adjustments per external reviews of the plan and approach. The final steps are to provide the report and data documentation, and to assist with interpreting and communicating the findings

Table I.3 highlights the respective roles of EERE staff and evaluators through the 14-step process shown in Figure I.5.

- **Step 1** • Begin an evaluation by defining the portfolio, preparing a logic model, and selecting elements for in-depth analysis
- **Step 2** • Identify next-best alternative and determine how to assess additionality
- **Step 3** • Estimate energy and economic impacts
- **Step 4** • Estimate environmental impacts
- **Step 5** • Estimate security impacts
- **Step 6** • Estimate knowledge benefits
- **Step 7** • Calculate economic performance metrics
- **Step 8** • Calculate remaining Effective Useful Life (EUL) effects
- **Step 9** • Perform sensitivity analysis
- **Step 10** • Provide a technological and context assessment
- **Step 11** • Report results
- **Step 12** • Document all input data, assumptions, calculations, and results
- **Step 13** • Use study findings to inform decision making and for effective communications
- **Step 14** • Implement routine tracking and compilation of data to support future study updates

Figure I.5 14 Step Evaluation Process

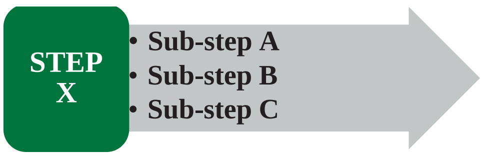
Table I.3 Roles of EERE Staff and of Evaluators throughout the Process

Evaluation Steps	EERE Staff Role	Evaluator Role
Before the evaluation begins		
	• Support the continuous tracking of technologies and compilation of data. • Prior to beginning the evaluation, verify that an evaluation of a R&D portfolio's ROI is needed and timely.	
After deciding to perform an evaluation		
Step 1	• Work with evaluator to finalize selection of the portfolio and technologies within the portfolio for in-depth analysis. • Connect evaluators with program informational sources, including cost data. • Participate as an internal reviewer and arrange for and oversee external and internal review of the proposed evaluation plan.	• Work collaboratively with program staff to define portfolio and projects/technologies for detailed evaluation. • Get the analysis underway, following instructions in Part II, Step 1.
Steps 2-11	• Answer evaluator's questions as needed.	• Estimate energy, environmental, energy security, and knowledge impacts. • Calculate economic performance metrics. • Calculate remaining Expected Useful Life (EUL) effects. • Perform sensitivity analysis. • Provide a formative analysis.
Steps 12	• Participate in the internal review of draft report and data documentation. • Oversee the external and internal review of the draft report.	• Submit draft report and data documentation for internal and external review. • Revise report and resubmit final draft publication report, accompanied by data documentation. • As necessary, work with a copy editor to prepare report for publication.
Step 13	• Schedule a program office briefing on study approach and findings. • Work with evaluator to prepare a 1-2 page Executive Brief that provides an overview of the findings. • Use study findings to inform decision making, as necessary. • Communicate findings to stakeholders inside and outside EERE.	• Prepare briefing slides and present seminar for EERE staff on study approach and findings. • Work with EERE staff to prepare a 1-2 page Executive Brief on findings. • Present study approach and findings in conferences and publications as desired (not required).
Step 14	• Implement routine tracking and recording of data within the program to support future analyses.	• Answer questions about the details of the study data as needed for EERE data collection.

PART II. Conduct an Evaluation Step-by-Step

Notation used in Part II

Each of the 14 steps to follow in conducting an evaluation is introduced with the following arrow symbol, on which is superimposed the step number in the rectangle, and a listing of multiple sub-steps within the body of the arrow. The sub-steps are lettered sequentially in the text.



Examples from past retrospective evaluation studies are presented for illustrative purposes throughout Part II, and are indicated in the text by the following symbol:

Specifications of calculation formulations are indicated in the text by the symbol:

Boxed text on a shaded field is used variously to highlight key points and to present examples.

For Background in Conducting PART II, see PART I

PART I introduces the Guide, explaining the approach taken and underlying concepts employed in PART II. It summarizes roles and responsibility in carrying out the 14 steps. Once the material in PART I is understood, it is expected that the evaluator will work primarily in PART II, returning to PART I only as needed for clarification of the approach and underlying concepts.

II.1 Begin an Evaluation

1. Begin an Evaluation

- Define a portfolio for evaluation.
- Assess evaluability of the portfolio.
- Select technologies from the portfolio for in-depth analysis.
- Characterize the portfolio and the selected technologies in the context of a logic model.
- Compile investment cost and other data.
- Describe qualitatively the elements of the portfolio not selected for detailed analysis.

Sub-section 1.B was prepared by Dr. Yaw Agyeman of Lawrence Berkeley National Laboratory

1.A Define a portfolio for evaluation

A starting point for the evaluation is defining an EERE portfolio for evaluation. The portfolio may be defined as:

1) An entire EERE program or group of programs that share common attributes;
2) A subprogram or group of subprograms within a larger program that share common attributes; or
3) A grouping of projects/activities that cut across several programs but share a common feature that makes it reasonable and desirable to group them.

EERE program staff may have defined at least a tentative portfolio for impact evaluation prior to engaging an evaluator. The evaluator, once engaged, may work with EERE staff to refine the portfolio definition. Whether defined in advance by EERE staff, or collaboratively with the evaluator, the following criteria are recommended for deciding on the portfolio:

- The grouping makes logical sense; for example, it may represent a portion of one of EERE's three major technology portfolio groups: renewable energy, energy efficiency, or transportation;
- The area of EERE investment has had sufficient time for commercialization or other implementation to have occurred;
- The portfolio as defined may help to balance the representation of EERE's diverse R&D groupings with those that have already received evaluation;
- The portfolio contains technologies that: (a) were not included in past EERE studies; (b) were included but had not at the time shown the degree of market penetration that has since occurred; or (c) were previously evaluated using an alternative approach not consistent with the approach presented in this Guide; and
- The portfolio as defined represents an area of EERE investment that has emerged as a priority with stakeholders.

The evaluator should explain in the final report why the portfolio is defined as it is.[21]

1.B Assess evaluability of the portfolio

It is important that a determination is made as to whether the defined portfolio is evaluable, that is, whether it is ready to be evaluated and conducive to evaluation. Depending on the scope, importance, and the evaluation budget, the evaluability assessment might be informal, or it may be more extensive. An informal evaluability assessment might be conducted as part of the background research for the study to be done. A formal evaluability assessment would be more extensive. In the first instance, the evaluability assessment must ensure that the evaluation focus is within the R&D scope.

The clear articulation of goals is the first step in an evaluability assessment. It is not uncommon for the evaluator to discover, upon arrival, that the program or portfolio to be evaluated lacks clear goals, and that this lack of clearly articulated goals, along with a lack of clarity of investment pathways, means that an evaluability assessment is necessary. Just as important is the acquisition of relevant data. The evaluator must determine, through initial consultation with program staff and stakeholders, that the requisite information that would be needed for the evaluation can be acquired.

In addition, the outcome of interest must be clear and flow logically from the investment under investigation. Moreover, it must be measured only when an impact could plausibly have occurred.

1.C Select specific technologies within the portfolio for in-depth analysis

From the portfolio, the evaluator and EERE staff will identify a selection of technologies for in-depth impact analysis. The highlighted box provides an example of specific technologies selected from within a subprogram of the Vehicles Technologies Office (VTO). If the technologies contained in the portfolio appear fairly evenly distributed in terms of the extent of their commercial development, the selection may be made by a random draw. However, if some of the technologies have shown more extensive commercial development than others (as often occurs in R&D programs), selecting those with more extensive commercialization offers evaluation efficiencies. [22]

Technologies selected for detailed analysis may include applications that lie outside the area targeted by the EERE program. At the same time, the study should report that the reported achievement was not within the program's focus. The second highlighted box in this section gives an example for the Geothermal Technologies Office (GTO), where the Advanced Polycrystalline Diamond Compact (PDC) drill bit was a technology selected for an in-depth analysis, and the study found a strong positive spillover impact on the oil and gas industry.

Table II.1 lists portfolios and technologies selected for detailed analysis in evaluation studies completed in 2010 and 2013. In

[21] The Program Office will make the initial decision on portfolio selection. In step 1, the evaluator may discuss the selection with program staff, and they may jointly agree to keep or to modify the selection. An evaluability assessment may also influence the final selection decision.

[22] See PART 1.2.3 for a discussion of how the distribution of project returns affects the selection process and, in turn, the efficiency of conducting the evaluation.

those five studies, the portfolios were defined along program or sub-program lines.

Technologies selected for detailed analysis might include any of the following types:

- Technologies embodied in a component, product, or a system;
- Technologies embodied in a new or improved process (e.g., improved deposition method for solar photovoltaic thin films);
- Technology platforms that have multiple and varied applications; and
- Infratechnologies that are used to improve performance or reduce cost but are not directly present in the products or processes they influence (e.g., new research tools, modeling capability, data bases, or test results).

The highlighted box provides an example of an infratechnology — "new research tools" — selected for in-depth focus in a past EERE R&D evaluation.

Example of New Research Tools Selected for Detailed Analysis:

An EERE evaluation study completed in 2008 included a portfolio of combustion technologies, designated the Advanced Combustion Engine R&D (ACE R&D) portfolio. The specific technologies from the portfolio selected for detailed analysis were new research tools:

- Laser diagnostic and optical engine technologies focused on heavy-duty diesel engines, and
- Combustion modeling –in particular KIVA modeling that simulates the fluid dynamics of combustion processes in internal combustion engines.

Not selected for detailed study, but included in the ACE R&D portfolio, were Combustion and Emission Control and Solid State Energy Conversion.

Laser and optical diagnostics and combustion modeling applied to heavy-duty diesel engines were selected in part because they are research areas with measurable milestones and outcomes that are directly associated with the ACE R&D subprogram’s research.

Example of Selecting a Technology whose Main Application was Outside the Program's Focus:

Advanced Polycrystalline Diamond Compact (PDC) drill bits were selected for detailed study in an evaluation that defined EERE's Geothermal Technology Office (GTO) investments as the portfolio. The PDC drill bits were designed better to withstand the high temperatures and hard rock encountered in drilling geothermal wells.
An early adopter of these advanced drill bits was the petroleum industry, where the advanced drill bits also offered substantial advantages over existing drill bits. Over the timeframe of the analysis, many more oil and gas wells were drilled than geothermal wells, making the benefits of the new drill bit in the oil and gas application area many times larger than in geothermal applications.

The application of the technology in the oil and gas industry in no way lessened the value of its benefits in geothermal applications. Rather, it increased total benefits and the social return on the GTO's investment in drill bits, which is a desirable outcome. Thus, it is acceptable to draw technologies for detailed analysis that have had large applications outside of EERE's initial intended focus. The study should in this case identify the application area as having a spillover benefit that goes beyond the geothermal industry targeted by the GTO investment.

Table II.1 Portfolios and Selected Technologies for Detailed Analysis (2013 and 2010 EERE Benefit-Cost Studies)*

Five Portfolios	Technologies within Each Portfolio Selected for Detailed Analysis
Energy Storage Technologies for Hybrid and Electric Passenger Vehicles and Light-duty Trucks (in the Vehicle Technologies Office)	• Lithium-ion (Li-ion) battery technologies for electric and hybrid cars and trucks • Nickel Metal Hydride (NiMH) battery technologies for electric and hybrid cars and trucks
Geothermal Technologies Office	• 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
Solar Photovoltaic (solar PV) Energy Subprogram of the Solar Energy Technologies Office	• Crystalline silicon PV module technologies, Thin Film PV module technologies, Manufacturing technologies, Technology infrastructure for measurement, characterization, and reliability
Advanced Combustion Engine R&D Subprogram of the Vehicle Technologies Office	• 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

* Note: In all of these examples, each portfolio is within a given program. However, a portfolio could alternatively be defined as crossing program lines or representative of the entire EERE.

1.D Characterize the portfolio and its components, including the selected technologies, in the context of a logic model

Using a logic model,[23] characterize the portfolio and the selected technologies. The logic model provides a model of how the elements of the portfolio were conceived, planned, expected to operate, and what they were intended to deliver. It is expected that the evaluator will review program and other documents and interview program staff to obtain the background information needed to develop this characterization of the portfolio.

Describe portfolio goals, objectives and strategies, and activities undertaken in support of goal achievement. The activities are here considered synonymous with the EERE interventions intended to bring about the desired change or impact.

The logic model representation of the portfolio should contain the basic elements shown in Figure II-1. The basic logic model elements are inputs or resources, major activities, outputs, intermediate outcomes, and ultimate outcomes and impacts. The intended audience is often also included, as shown. The logic model prepared for the portfolio should flesh out these basic elements in sufficient detail to depict the portfolio as defined for the study. It can be presented using a linear depiction, as shown.

The logic model should be useful in explaining, presenting, and understanding the overall portfolio. But it also should provide sufficient detail that each of the technologies selected for detailed analysis can be located within the portfolio's major activities. The logic model is a starting point and a tool for planning the evaluation—both the quantitative analysis of the selected technologies and the qualitative assessment of the parts of the portfolio not selected for detailed analysis.

1.E Compile investment costs and other portfolio data

Portfolio investment costs are defined as yearly expenditures incurred by DOE in implementing the portfolio's activities over the period covered. The data should include the entire portfolio cost; they should omit nothing within portfolio scope.[24]

In the case of the five portfolios evaluated through 2013, the issue of other DOE investment costs (outside of EERE) has arisen only once: The development of EERE's Advanced Combustion Engine (ACE) R&D's portfolio of technologies relied on a special facility, the DOE Office of Science's Combustion Research Facility (CFR), in addition to the EERE's ACE R&D's investment. Portfolio investment costs in this case include total ACE R&D investment costs plus the CRF research budget.

Economic return is computed by comparing the benefits of the selected technologies against total portfolio investment cost. Nonetheless, the evaluator is encouraged to also obtain investment costs for the individual technologies selected for detailed analysis if these costs are available. Individual investment costs for a past

[23] There is extensive literature on logic models and their development. A logic model development guide, for example, is provided on-line by the W.K. Kellogg Foundation (see www.wkkf.org). Guidance is also provided by McLaughlin and Jordan (2010, 2nd ed.), and examples of logic models for public R&D programs can be found in Jordan, et al (2014).

[24] Directly related expenditures by other parts of DOE are expected to be included, but related expenditures by other federal agencies or by other organizations are not to be included.

evaluation are illustrated in the text box. The purpose is to know the share of total portfolio costs that are comprised by costs of the selected technologies. Knowing the share gives a sense of what portion of the portfolio has been analyzed in detail. See highlighted box.

Portfolio Investment Costs and Selected Technology Investment Costs

In the 2010 evaluation of EERE's solar photovoltaic energy R&D, the study defined the portfolio investment cost as the total EERE expenditure on Photovoltaic Energy Systems between 1975 and 2008. The total was $3,710 million in 2008 dollars. This is the amount that was compared against benefits to compute return on EERE's investment.

The portfolio included the following three initiatives for which technologies research was selected for detailed analyses: (1) the Flat-Plate Solar Array Project (FSA) that had an investment cost of $535 million; (2) the Photovoltaic Manufacturing Project (PVMaT) that had an investment cost of $200.7 million; and the Thin-Film PV Partnerships Program (TFP) that had an investment cost of $294.3 million.

The sum of the investment cost for the three initiatives examined was $1,030 million, while the cost for the entire solar PV R&D portfolio was $3,710 million.

Thus, the combined investment cost of the selected technologies amounted to 28% of portfolio investment cost.

Total program and subprogram costs should be available for past years from the relevant EERE program. However, costs for individual technologies within a portfolio may be less readily available.

Because total portfolio costs are essential to computation of the desired economic performance metrics, obtaining them is imperative; the cost data for individual technologies is desirable, but not essential for the evaluation.

Table II.2 EERE Geothermal Program Cost, 1976-2008 (thousands $2008)

Year	Program Expenses
1976	$92,819
1977	$130,899
1978	$288,654
1979	$367,328
1980	$316,935
1981	$324,090
1982	$142,327
1983	$93,412
1984	$41,677
1985	$57,793
1986	$45,668
1987	$34,891
1988	$35,623
1989	$30,829
1990	$26,832
1991	$43,236
1992	$38,143
1993	$31,619
1994	$31,251
1995	$50,360
1996	$38,384
1997	$37,373
1998	$36,402
1999	$35,194
2000	$28,554
2001	$32,205
2002	$32,149
2003	$30,550
2004	$29,348
2005	$27,414
2006	$24,478
2007	$5,107
2008	$19,307
Undiscounted Total	$2,600,851

Source: Gallaher et al. (2010).

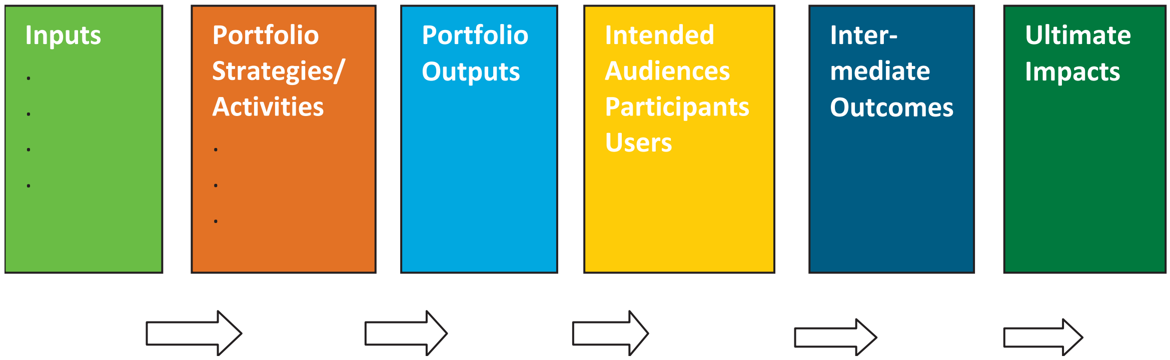


Figure II.1 Simplified Portfolio Logic Model Showing Basic Elements

EERE program staff have responsibility for obtaining and providing portfolio costs to the evaluator. As soon as the portfolio is defined, the evaluator should request the cost data from the program, and program staff should take immediate steps to provide the investment cost data for the relevant portfolio, and for the selected technologies if available.

Portfolio investment costs should be presented year-by-year over the entire period of EERE's investment in the portfolio. There should be clear designation of how the dollar values are expressed, i.e., in actual (current) dollars or in constant dollars, and, if the latter, it should be made clear in what base-year dollars they are expressed and what was the source for the conversion from current to constant dollars. It is preferred that the evaluator receives the expenditure data from EERE in current dollars and convert to constant dollars as part of the evaluation (as treated in Step 7).

Table II.2, shown in the highlighted box, provides an example of year-by-year portfolio investment cost data that have been converted to constant dollars. The data are from the 2010 impact evaluation report on geothermal technologies. In this case, the portfolio was the entire GTO program. The year-by-year investment costs are carried forward into Step 7, and used to calculate economic performance measures.

Additional data that the evaluator should seek to compile while performing this initial step are data that describe the portfolio over time in terms of its activities, participants, technical achievements, barriers overcome, outputs, and outcomes. A search, for instance, may turn up earlier studies that may show how key metrics, such as cost and performance, have changed over time.

1.F Describe qualitatively the elements of the portfolio not selected for detailed analysis

While the quantitative analysis centers on the technologies selected for detailed analysis, it is important also to provide a qualitative review of other elements in the program portfolio. What other research areas/ technologies does the portfolio contain? What is the status of these other elements? To what extent were there technical failures? To what extent are commercialized technologies still in an early market stage? How are they related to the technologies selected for detailed analysis?

The aim is to give a sense of the likely overall impact of the portfolio once the detailed quantitative analysis of the selected technologies is completed. Is there reason to believe that the other elements in the portfolio at a minimum will not offset positive impacts of the selected technologies? Is there reason to believe they have provided additional benefits? Might they provide additional benefits in the future? What type of benefits? What share of the total portfolio cost do they represent?

The qualitative assessment of elements of the portfolio that are not selected for quantitative evaluation should be documented in the study report.

II.2 Identify Next-Best Alternative and Assess Additionality

2. Identify Next-Best Alternative and Assess Additionality

- Identify next-best alternative for each technology selected for detailed analysis.
- Assess additionality using the most rigorous evaluation design that is feasible.

Sub-sections 2.B.1, 2.B.2, 2.B.3, and 2.B.4 were prepared by Dr. Yaw Agyeman of Lawrence Berkeley National Laboratory

Step 2 guides the estimation of energy and other resource effects resulting from end use of the technologies selected for detailed analysis. This step proceeds through two sub-steps (2.A and 2.B), with emphasis on identifying the next-best alternative for comparison and treating additionality in the analysis (i.e., the extent to which the estimated impacts have resulted from the EERE investment).

2.A Identify next-best alternative for each technology selected for detailed analysis

There are 3 tasks within this sub-step, called out by headers. The first is to develop an in-depth understanding of the selected technologies that was begun in Step 1. The second is to characterize the selected technologies as infratechnologies, technology platforms, product technologies, or enabling product technologies. The third is to define the next-best alternative.

2.A.1 Develop an in-depth understanding of the selected technologies

The objective of Step 2.A is to identify what alternative each of the selected technologies must be compared against in order to determine its resource effects. To do this, it is necessary to have a solid understanding of the technologies selected for detailed analysis.

Continue the compilation of secondary data that was begun in Step 1, now focusing on the selected technologies for detailed analysis. Review technology assessments from the peer-reviewed literature. Look for accounts of events, breakthroughs, and explanatory factors in journal publications, reports, and presentations, taking note of mentions of EERE and/or DOE’s programs, investment, and technical support. In addition to researching trends for the period after EERE's investment began, consult contemporary resources that document the state of the technology prior to that period. This "before-DOE's investment" investigation is necessary in order to acquire insight into the state of the art, challenges, and stated needs that led to EERE's involvement, and to establish the time period of analysis. To assess technical and market trends look for information on the relevant EERE programmatic initiative(s), technical and market trends, and funded entities for each selected technology or technology family in the subject portfolio. See also the results of Step 6 on knowledge benefits if that step is conducted concurrently or in advance of this step, to learn what inventions have resulted from the EERE funding and who has used them.

Resources relevant for finding secondary data include:

- Peer-reviewed scientific, engineering, and economic literature;
- Business and industry literature and reports prepared by professional and industry associations;
- Policy briefs, technical reports, and annual reports prepared by DOE offices and national laboratories;
- Business and industry press releases;
- Financial and market analysis reports; and
- Economic and technical histories in the area of investigation.

Assemble a timeline of EERE and non-EERE initiatives and technological milestones and achievements. The timeline should contain the following:

- Time frames of EERE and non-EERE programmatic initiatives;
- Periods of performance for firms working on EERE-funded and co-funded initiatives;
- Targeted achievements and actual outcomes for firms receiving EERE support and, if possible, firms not receiving EERE support;
- Technological and market milestones for technologies and technology families included in the detailed analysis; and
- U.S. and non-U.S. policies or other exogenous shocks.

Conduct initial unstructured interviews with a subset of knowledgeable individuals from government, national laboratories, academia, industry consortia, and firms. Candidate interviewees must have industry, academic, and/or management experience germane to the selected technology families. Examples include institute directors, program leaders, research directors, chief technology officers, and senior scientists working in the field.

Discussion topics for initial interviews should include, but not necessarily be limited to:

- State of the selected technologies and their rates of progress prior to EERE investment;
- Significance of EERE investment and support in introducing the new or improved emerging technologies or technology families or in revitalizing maturing technologies;
- Main technical challenges/barriers to be overcome;
- EERE goals, strategies, and targets;
- Technical performance characteristics that can be used to assess technological progress across the technology families (e.g., reliability, production cost, energy density, watt rating);
- Technical contributions of EERE and national laboratory staff relative to academic and industry researchers' contributions;
- Infratechnology, technology platform, product technology characteristics of the selected technologies;

- Areas of application of the technologies,value chain characteristics and competitive landscape;
- Alternative funders to EERE for technology development;
- Demand-side initiatives and their relationship to the technology development initiative along dimensions related to technological progress and timing; and
- Opinions about next-best alternatives to the technologies selected for detailed analysis from the portfolio.

2.A.2 Characterize the selected technologies as infratechnologies, technology platforms, and/or product technologies (including enabling product technologies)

As part of the in-depth characterization of the selected technologies, define and characterize the economic role of each technology according to a typology that characterizes a given technology by its infratechnology, technology platform, and product technology content. Correctly characterizing the technologies being evaluated is essential for next-best alternative selection and also for the quantification of additionality in sub-step 2.B. A given selection of technologies, or even a given technology, may contain more than one type of technology characteristic, which may necessitate separate treatment of technologies by type in the next-best alternative analysis.

Technology typology:

Infratechnologies are technologies that influence the efficiency of R&D, production, and marketing of other technologies. Infratechnologies often represent advances in and understanding of scientific and technical phenomena, such as improvements in measurement and testing, concepts, tools, and techniques. Examples of infratechnologies are building efficiency standards, appliance standards, test methods, modeling capabilities, scientific databases, equipment calibration procedures, standard reference materials, and research tools and user facilities.

Benefits of infratechnology may be measured, for example, in terms of gains in efficiency in applications to which they are applied and the resulting acceleration of the introduction of more efficient or productive products and services. The vehicle combustion study prepared by Link (2010) assessed the economic benefits associated with infratechnology. That study analyzed the use of laser and optical diagnostics and combustion modeling (a suite of infratechnologies) to improve combustion in heavy-duty diesel truck engines by advancing understanding and control of the in-engine combustion process. Application of infratechnology in R&D supports the development of technology platforms.

Technology Platforms are precompetitive prototypes and concepts that serve as proof-of-concepts and demonstrations of the commercial viability of new end-use products, processes, or services. They have alternatively been termed "generic technologies." Technology platforms may support the creation of multiple products and processes. Technology platforms are often a precursor to product technologies.

There are numerous EERE-supported technology platforms that serve as the basis for multiple downstream products. One example is novel wind turbine blade designs, which improved the efficiency of wind turbines relative to preexisting turbines, and were adopted by multiple producers for a variety of commercialized wind turbines.

Product Technologies are technological innovations directly embodied in and closely identified with a specific new or improved product, process, or service.[25] An example from the first round of EERE benefit-cost evaluation studies is geothermal high-temperature cement innovation embodied in the product, ThermaLock cement (Gallaher et al, 2010).

Product technologies can be enabling in the sense of making possible the wider use of another technology. Examples of enabling product technologies are advanced batteries for powering electric cars, and essential for their expanded use; and binary cycle geothermal plant technology which expanded the geographical regions over which geothermal plants can be located to include lower temperature applications.

Table II.2-1 presents technologies analyzed in previous EERE benefit-cost studies and their characterization.

2.A.3 Define the next-best alternative

Next, the evaluator identifies the next-best alternative that would have been used or would have occurred as an alternative scenario in lieu of each technology or technology family grouping being analyzed quantitatively. The merits of the technology being analyzed are judged against those of the best alternative, i.e., the best technology alternative that would otherwise have been used. The term "next-best alternative" is synonymous with the term "defender technology."

For a retrospective benefit-cost evaluation such as that covered by this Guide, the next-best alternative is defined by looking back to the time the investment decision was made for the new technology. Note that the next-best technology at the time of the investment decision is not necessarily today's next-best alternative. Also note that the analysis must account for the next-best alternative's technological progress over the period of the evaluation. In other words, do not assume that the next-best alternative technology's technical performance characteristics necessarily remained fixed.

In the case of a comparison against an alternative counterfactual scenario, the next-best alternative technology is the technology as it would have existed in the counterfactual scenario. For example, the next-best alternative for use in the solar photovoltaic evaluation prepared for EERE (O'Connor et al., 2010), was the state of solar photovoltaic modules in the absence of DOE support. By assessing counterfactual progress through in-depth survey procedures and technical assessments, O'Connor et al. constructed a dynamic counterfactual scenario against which actual progress was compared to quantify economic benefits. Many technologies (e.g., solar photovoltaic modules and wind turbines) existed prior to DOE involvement, such that DOE played a role in advancing their development, rather than in creating them.

The next-best alterative analysis should consider not only domestically sourced alternatives but also internationally available alternatives. For example, in the case of the Photovoltaic Energy Systems benefit-cost analysis (O'Connor et al, 2010), contemporary programs funded by other national governments were reviewed for a

[25] Note, too, that some product technologies are so ubiquitous that they become defacto standards (having quasi-public good content) despite no formal designation as such (e.g., Microsoft Windows).

next-best alternative but none was found.[26] This international look is important because of the global nature of the technologies that EERE supports.

Conditions of use—as well as technology type—can affect the choice of next-best alternative. An illustration is provided by the evaluation of geothermal binary-cycle plant technology. In the evaluation of GTO R&D, binary-cycle plants were considered in two applications: (1) Application of binary-cycle plant technology to take advantage of lower temperature reservoir resources, in which case the technology enabled the use of geothermal plants where they otherwise could not effectively be used; and (2) Application of binary-cycle technology where higher temperature resources existed and flash geothermal plant technology was a viable alternative. In the former application the technology is geothermal enabling; without the binary-cycle technology, geothermal could not be used and the next-best alternative is a conventional power plant. In the latter application the binary-cycle technology functions as an improved product technology offering productivity gains over the next-best geothermal plan alternative, a flash geothermal plant. Thus, the application area will, in some cases, affect the appropriate specification of next-best alternative, and therefore should be taken into account by the evaluator.

Energy and other impacts of the batteries derive from their use in hybrid and electric vehicles. Therefore, a dynamic counterfactual scenario was constructed of market adoption of hybrid and electric vehicles, given the best available battery technology that would likely have been available in absence of EERE's battery R&D.

In the case of a simple product technology, the identification of the next-best alternative tends to be more straightforward than for the other technology types. Geothermal high-temperature cement provides an example. The next-best alternative at the beginning of the study period and continuing throughout the study period was an alternative cement, identified as Portland Cement.

It is a requirement that the 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 the rationale. Table II.2-1 gives examples of the next-best alternatives identified by recent EERE benefit-cost studies.

To facilitate understanding, it may also be helpful to consider how not to define the next-best alternative. For this purpose, the text box gives an example in which the choice of next-best alternative is not appropriately aligned with the technology under evaluation. The example provided in the highlighted text box is of inappropriate alignment for a *hypothetical* wave technology.

[26] In 1974, following the 1973 oil price shocks, Japan created an energy R&D program called the Sunshine Project, which was intended to support solar photovoltaics, coal gasification and liquefaction, geothermal, and hydrogen technologies. The project was organized by the Agency of Industrial Science and Technology within the Ministry of International Trade and Industry. That program's work was reviewed to see if technologies could have emerged and entered the U.S. market from it instead of the DOE-sponsored program. It is important to review such efforts to ensure that the counterfactual scenario is appropriately constructed.

Table II.2-1 Technology Characterizations and Next-Best Alternatives in EERE Benefit-Cost Analyses

Study	Technology Focus	Technology Characterization	Next-Best Alternative
Advanced Combustion Engine (ACE) R&D Subprogram	Laser and optical diagnostics	Infratechnology	The state-of-the-art in diesel engine design and related brake thermal efficiency (BTE) that existed prior to 1995.
Vehicle Technology Office Energy Storage Subprogram	Li-ion and NiMH energy storage technologies	Enabling product technology	Lower market adoption of electric and hybrid versions of passenger vehicles with inferior battery technologies
Geothermal Technology Office R&D	Polycrystalline Diamond Compact (PDC) Drill Bits	Product technology	Roller-cone drill bit technology that existed prior to introduction of the PDC drill bit and continued in use over the study period as market penetration of the PDC drill bit occurred.
	Binary cycle power plant • for reservoir temperatures in the range of 150 to 190°C	Product technology	Geothermal flash plant.
	• for reservoir temperatures below 150°C	Enabling product technology	Conventional power plant.
	TOUGH reservoir model series and related reservoir models	Infratechnology and technology platform	"Lumped parameter" models used before capabilities for detailed computer simulation of reservoirs were developed.
	High-temperature geothermal well cements	Product technology	Existing Portland cements.
Solar Photovoltaic Energy Systems Subprogram	cSi modules and thin-film modules	Technology platforms and product technologies	Inferior solar photovoltaic modules due to slower progress without EERE investment.
	Standards and measurement science and infrastructure	Infratechnology	

Thus, appropriate next-best comparison can vary depending on whether the technology is a product technology (enabling or not), a technology platform, or an infratechnology. It can also vary according to conditions of use. These variations have been demonstrated in the examples given above. They point to the need for evaluators to be careful and diligent in specifying the next-best alternative for comparison. The choice is critical because the basis of the comparison is an important determinant in the estimation of impacts.

Do not proceed with economic analysis until the technology characterization, the specification of the next-best alternative, and the impact categories align in an internally consistent narrative, and there is no disconnect or contradiction with the results of the desk analysis.

2.B Assess additionality using the most rigorous evaluation design that is feasible

An evaluation objective is to find the social return on EERE's investment. This requires going beyond estimating benefits of the subject technology in comparison with its next-best alternative. It is also necessary to assess to what extent the estimated benefits have resulted from EERE's investment rather than from other sources.

Hypothetical Example of Incorrect Next-Best Alternative

In 1980 the first commercial wave energy system was introduced to the market. Although the system had poor reliability and efficiency, there was a sufficient value proposition for some applications and for some consumers. A small number of systems produced by multiple firms were installed between 1980 and 1990.

In 1990, a Federal agency launched a series of initiatives aiming to improve the efficiency, quality, and reliability of these energy systems. The agency-sponsored initiatives included test beds, standards, production technology development, new blade designs (introduced commercially in 1995), and other technologies.

Experts stated that the wave energy system was accelerated by more than 10 years, and, indeed, there were impressive gains along all the technical and economic performance characteristics of interest. The rate of growth in system installation increased 10% annually between 1995 and 2010.

In conducting the evaluation and in specifying the next-best alternative in terms of a counterfactual scenario, the analyst delayed the introduction of wave energy systems by 10 years, citing the acceleration claims of interviewed experts. All of the technologies sponsored by DOE were necessary for successful commercial systems, the analyst argued, and, without all of them system deployment would have been delayed by 10 years. Over the 10-year delay, the next-best alternative was defined as traditional fossil fuel systems.

Although the analyst correctly characterized the technologies in economics terms, he incorrectly established the counterfactual scenario and therefore the next-best technology alternative. In actuality, introduction of wave energy systems was not accelerated by 10 years, rather progress in wave technology was. Systems were available prior to the Federal program, and, while growth and progress would have been comparatively anemic without technological advance, there would have been some progress. The appropriate next-best alternative to improved wave technology development would have meant reviewing performance and economic characteristics without the improvements. The time series of benefits associated with advances in wave energy systems should have been estimated using a comparison of actual wave energy systems' performance characteristics in a given year with what they would have been for the counterfactual case of performance characteristics absent the advances.

There are three types of study design: experimental, quasi-experimental, and nonexperimental. The following subsections identify essential differences among these designs and discuss their strengths and weaknesses.

This sub-step is divided into three tasks, identified by sub-heading. The first is to choose the study design. The second is to model how additionality occurs. The third is to strengthen the counterfactual approach, when counterfactual evaluation methods are used.

2.B.1 Experimental study design

An experimental study design is the most robust of the three evaluation study designs, because it compares groups that are identical except for having received or not received the intervention in question. Thus, any measured differences in outcome between the two groups can reasonably be attributed to the intervention.

Prior to the intervention, the study population is randomly assigned into an intervention group and a control group. After the intervention, pre-post observations from each group are compared. It is a design widely used in medical and laboratory research.

Experimental design is generally not practical or feasible for use in retrospective evaluation of research, development, and technology programs, where companies self-select to participate or not; participants are known and may differ in a number of ways, such as size and age; populations tend to be small; and events occur in the field rather than in controlled environments.

2.B.2 Quasi-experimental study design

This design is similar to an experimental design, with the exception that participants are not randomly assigned into intervention and control groups, and a comparison group is constructed as a proxy control. Quasi-experimental research designs compare observations for those in the intervention group and those in the proxy control group to assess whether there are significant differences in outcome for those who received the subject program intervention versus those who did not. The more the intervention group and the proxy control group are alike in all ways except receiving or not receiving the subject program intervention, the more likely that observed difference in outcomes has resulted from the subject program intervention. If the comparison group is poorly constructed and validity threats are unsatisfactorily treated, a quasi-experimental design may not provide a robust assessment of additionality.

2.B.3 Nonexperimental study design, including the counterfactual approach

A nonexperimental study design lacks a proxy control group comprised of those who did not receive the program intervention. Thus, nonexperimental study designs do not provide as strong a basis for establishing causality as does experimental or quasi-experimental designs. Yet, in many circumstances, they are the only available design.

When neither the construction of a true control group (experimental design) nor a proxy control group (quasi-experimental design) is feasible, the evaluator may use a counterfactual approach to increase the robustness of the approach for assessing additionality. This may entail interviews of those who received the intervention (i.e., participants) to assess what they would have done in absence of the intervention, and in effect use the results as a "pseudo comparison group"— i.e., the participants in actuality versus the participants acting in counterfactual mode.

Alternatively, the evaluator may use interviews of independent experts (i.e., nonparticipants) and secondary data to establish a counterfactual case.

As another alternative, the evaluator may employ both of the above—interview of participants and interview of independent experts—in conducting a nonexperimental design using a counterfactual approach.

The use of a counterfactual scenario, while not as strong a basis for establishing additionality as an experimental or quasi-experimental design, is nonetheless better than a nonexperimental design without the use of a counterfactual.

2.B.4 Order of preference in selecting study design

For evaluations covered by this Guide, the EERE standard for design selection is:

- Chose experimental design— the gold standard for evaluation research — when possible. If it is not possible to use experimental design, then the evaluator must consider using a quasi-experimental design.
- If data and evaluation conditions exist on which a proxy control group[27] can be established, then use a quasi-experimental design.[28]
- If it is not possible to use quasi-experimental design, then the evaluator must use nonexperimental design including the counterfactual evaluation approach.
- A nonexperimental study design with counterfactual method can be strengthened through the use of mixed methods.[29] For instance, a counterfactual design combined with use of additional methods is preferred to use of a counterfactual design alone. Mixed methods could take the form of using different data collection and analysis methods with the same population, or using different sources of data across different sub-populations within the study population, patent citation analysis, historical tracing analysis, and network analyses. For example, an assessment of the impacts of the Vehicle Technologies Office's investments in energy storage technologies used patent citation analysis to provide evidence of documented linkages between patents resulting from EERE-sponsored R&D and advanced battery patents of leading research organizations. In a different assessment, such as a building technology assessment, one might be able to use different types of data (evaluation, measurement and verification; billings; surveys; focus groups) in the R&D study.
- Nonexperimental designs that do not include the counterfactual evaluation method are unacceptable to EERE.

2.B.5 Using a counterfactual approach to assess additionality

When a nonexperimental, counterfactual approach is used to assess additionality, the evaluator should provide a robust analysis. The following are suggested ways for providing a robust counterfactual analysis when (a) interviewing/surveying participants about what they would have done had there been no EERE investment; and (b) interviewing/surveying nonparticipant

[27] While it is generally not possible outside an experimental design to draw a true control group—for which members of the group differ from the participant group solely in terms of not receiving the subject intervention, there are techniques that can be employed to control for at least part of the differences and bring a proxy control group closer to a true control group.

[28] An example of when a quasi-experimental design could be performed in the R&D evaluation context, is when it is feasible to identify firms who receive DOE R&D funding awards as well as firms who applied but were rejected because funding was not available for them (i.e., they were nearly as qualified in their proposed research to be awarded funds, but just missed the cutoff). Those just missing the award cutoff could comprise a comparison group to enable a quasi-experimental design to proceed as the design method. Still, unless the firms were similar to each other in other attributes, such as size, age, innovation propensity, and other factors that might cause difference in outcomes, steps would be needed to control for these differences.

[29] Mixed methods are complementary data/analysis that produces additional lines of evidence to strengthen the results/findings.

experts about what they think would otherwise have happened:

(a) Providing a robust additionality analysis when interviewing/ surveying participants about what they would have done had there been no EERE investment:

Who and how many participants?

- If participants received equivalent EERE support, draw a random sample for interview.
- If the population of participants is large and heterogeneous in terms of the EERE support they received or have other characteristics, then in keeping with the portfolio approach, segment the population in subgroups based on distinguishing characteristics. Draw interview samples from each subgroup. Justify the sample design.
- If the population of participants is small and heterogeneous, oversample on those who received the greatest amount of EERE support, or if there are too few participants to support a random sample then include 100% of the participants in the interview/survey. Justify the sample design.

What to ask?

- Design questions are to be free of bias, to have the same meaning for all those interviewed, and to be carefully crafted to get at the desired piece of information. If an interview guide is used it must be at least semi-structured.
- Establish when the participant first became aware of EERE support programs.
- Establish baseline technical and financial performance metrics relevant to the evaluation. Review technology progress over time with participant.
- Relate EERE program to participant's technical and performance metrics. Ask what the participant would have done had they not participated in the EERE programs.
- Ask participants to rate the influence the EERE investment from the support program had on their R&D efforts. Establish what they would they have done differently, and how those actions would have affected their performance metrics.

How to interpret results?

- Use the interview/survey results to develop a counterfactual scenario.
- Compare the actual behavior of participants with the counterfactual scenario to estimate additionality, taking account of variability in responses.
- If the population of participants is heterogeneous, weight responses by market size or whatever measure is to be used to aggregate responses and/or scale to industry-level results.

(b) Providing a robust additionality analysis when asking nonparticipant experts what they think would otherwise have happened:

Who and how many experts?

- Interview or survey EERE-funded principal investigators, EERE and other DOE programmatic and technical staff, executives with industry and trade associations, U.S. and international academic researchers, and other experts with significant germane industry, academic, and/or management experience.
- Although there is no specified number of experts or participants that must be interviewed/surveyed, evaluators must report descriptive statistics for the populations, for those

interviewed/surveyed, and for impact data, including mean, median, standard deviation, and the number of respondents.

- Increase the number of experts, such that the results are not dependent on the judgments of a few experts, especially when their views are widely divergent. Provide mean, median, and standard deviation, and confidence intervals for key impact result parameters.
- Ensure that the sample of interviewed and/or surveyed experts includes non-DOE-funded experts.
- Ensure that experts are qualified through professional experience to respond to questions about early DOE or EERE initiatives before asking them to provide assessments of pre- and/or post-DOE engagement.
- Indicate how experts were selected and what part of the industry value chain they represent.
- Consider how likely it is that results would be significantly different simply if different experts had been chosen.

<u>What to ask?</u>

- Provide experts advance materials including the timeline (in Step 2.A) and an initial list of rival explanatory factors (see 2.B.3) assembled earlier for their review prior to the interview time.
- Ask the experts to comment on or offer any corrections to the timeline as part of the process of discussing rival explanatory factors and before they provide judgments.
- Assemble question topics carefully to query on firm-specific and industry-level technical progress, with an emphasis on the technical and/or cost performance characteristics.
- Begin by reviewing observed technical progress with the experts, and then determine what they think progress would have been in the absence of the R&D enabled by EERE funding and the technical support and infrastructure provided by EERE. Determine technological progress not only for the technology of interest but also the next-best alternative.
- Query changes in market behavior, resource efficiency, resource productivity, rate of adoption, market penetration, and acceleration effects, depending on the expert's area of specialty.
- Capture impact data not only as point estimates but also as ranges for sensitivity analysis.

<u>Confirm at interview or survey close that judgments offered by the experts on counterfactual behavior reflect solely the effect resulting from subject EERE intervention.</u>

- Be sure the expert gives careful consideration to rival explanations factors when making final judgments, e.g., the normal patterns of technology maturation, business cycle impacts, changes in the costs of the factors of production due to factors other than the EERE intervention, investments by other private sector entities, other DOE and non-DOE actions by public entities in the U.S. and abroad, and demand-side policies such as tax credits.
- If it is not possible for the expert to isolate the EERE-only effect, then apportion benefits using the share of EERE, other sources of public funding, and private funding for the outcomes.

<u>How to interpret results from either participant or nonparticipant experts?</u>

- If economic models are populated using firm-level responses as opposed to the industry-level responses, ensure that appropriate data for weighting the response (e.g., production volume, installed capacity) are collected. These must be applied to each individual response when scaling to industry-level impacts.

- Aggregate responses such that firm- or individual-specific responses are appropriately masked to protect any company proprietary data.
- Fully document the number and distribution of responses, including providing the frequency and the standard deviation of the mean.
- Prepare to test the sensitivity of analysis results to uncertainty arising from variation in responses by using a 95% or 90% confidence interval, and specify the interval used.
- Compare results to findings from the literature review, market and technical trends assessment, and timeline prepared earlier in Step 2, as well as with the R&D knowledge linkage analysis (Step 6).

2.B.6 Improve the reliability of the additionality assessment[30]

When using a non-experimental study design or often when using a quasi-experimental design, additional effort will be needed to improve the reliability of the additionality assessment. One approach is to identify the mechanism by which additionality is expected to have occurred. This could be based on information obtained from the logic model, records on how resources were used and what activities were undertaken, as well as from interviews with experts. Table II.2-2 illustrates potential ways that additionality may occur. For instance, a program investment may accelerate technology development and commercialization, leading to an earlier accrual of benefits than would have resulted otherwise. Alternatively, EERE investment may provide incentive to private companies to broaden the scope and scale of their research, such that spillover effects are increased. Another mechanism is that EERE investment may foster collaborative research or provide special facilities shared by multiple companies, thereby eliminating duplicative research and lowering overall R&D costs for a given level of benefits. The EERE investment may also enlarge markets by increasing customer awareness and acceptance of emerging technologies, such as through demonstrations, standards, and purchase incentives.

Knowing how the intervention has likely altered the outcome over what it otherwise would have been is helpful in computing the quantitative effects of additionality. If the effect is acceleration, for example, a lag effect may be used to show a slower rate of progress in benefit accrual without the intervention. An expansion of research scope and scale may be analyzed as a larger stream of benefits than would have otherwise occurred. Cost-reducing actions, such as fostering collaboration and providing special shared facilities may be analyzed as an increase in the investment cost that otherwise would have been required to provide the same level of technical performance. An expanded market may be analyzed as an increase in the use of the technology.

The point is not to provide here an exhaustive treatment of how additionality of various interventions are treated quantitatively, but rather to note that it may be helpful for the evaluator to translate the "how" into a computational procedure that

[30] As explained in sections 2.B.1 and 2.B.2, the assessment of additionality is internal to an experimental or robust quasi-experimental study design, and the use of these supporting assessment techniques may not be required when the study design is sufficiently strong.

can be used to estimate the share of benefits that resulted from the intervention.

In addition, when using a non-experimental study design or often when using a quasi-experimental design, always strengthen the assessment of additionality by explicitly identifying and systematically eliminating rival explanations for observed impacts. Identifying and eliminating rival explanatory factors as the cause for an observed effect is a key element in establishing additionality when the evaluation study design lacks robust control or comparison groups to accomplish this goal. Examples of rival explanatory factors are energy tax incentives such as the production tax credit (PTC), interventions from other entities such as a utility rebate program, and sociocultural factors.

Table II.2-2 Illustrative Ways that Additionality May Occur

Additionality Effects	Examples
Accelerating technology development & commercialization	• Expanding R&D funding to speed achievement of technical goals and commercialization.
Broadening the scope of private-sector R&D	• Increasing the scope and scale of private-sector R&D to overcome more difficult technical challenges with greater spillovers and social return.
Reducing redundancy in pre-competitive private-sector research, which reduces the costs of technology advancement	• Fostering collaborative R&D to develop pre-competitive technologies that serve an entire industry, to avoid investment redundancy
Enabling development of new research infratechnologies such as testing facilities, databases, research tools, standards, and models that will make an entire industry more efficient and which individual companies are unlikely to undertake	• Providing specialized facilities, services, and research tools needed by an entire industry to make technical advances.
Increasing the size of the market and use of the technology	• Reducing barriers to market adoption, e.g., through demonstrations, information, training, and standards and certification activities • Increasing access of U.S. firms to global markets.

In randomized control trials (RCTs) the use of randomization theoretically eliminates the influence of potential rival explanatory factors, known and unknown, across the treatment and control groups. The lack of randomization in quasi-experimental and nonexperimental designs imposes the need for careful treatment of potential confounders, rival explanatory factors.[31]

[31] Rival explanatory factors and confounders are used interchangeably in this guide. A rival explanatory factor that is not identified and its effects accounted for will "confound" the findings, which is to say that the intervention might be wrongly viewed to have caused the effect due simply to the fact that it operated at the same time as the true causative factor, or was correlated to it and to the outcome in some other way.

The evaluator must explicitly identify and list the major rival explanatory factors. Once identified, the following steps are recommended:

1. Develop an initial timeline for the rival explanatory factors
2. Engage industry experts and study participants to clarify and refine the accuracy and completeness of the explanatory factors timeline
3. Use the refined timeline to support the subsequent analysis.

Figure II.2 presents an illustrative example of what such a timeline of explanatory factors might look like.[32] Developing the initial timeline for rival explanatory factors provides the evaluator an explicit view of the major, known factors that could confound findings of effects, as well as the occurrence of these factors relative to the outcome. This explicit exposition is important to do early in the evaluation process because, during analysis, one of the considerations for determining possible confounding is whether there has been a plausible time lag between the major potential causes and the effect. Every major factor, including the EERE intervention, must be subjected to this basic determination.

Data collection instruments designed for the study should explicitly inquire about the major rival explanatory factors to ensure that the study participants base their responses on the same underlying assumptions.

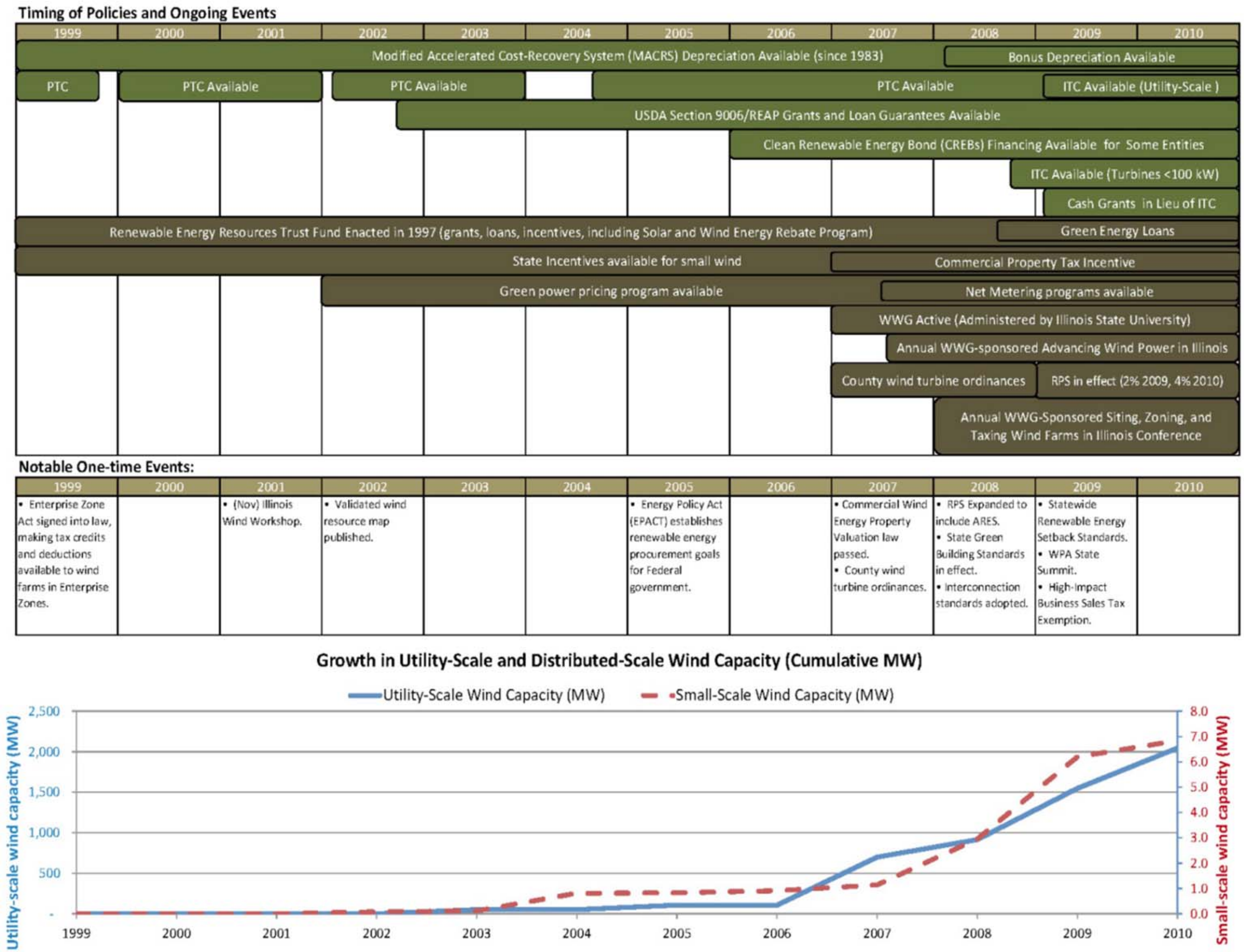
Some rival explanatory factors may not lend themselves easily to a timeline. For example, a sociocultural factor might be a factor of interest in terms of its effects on the outcome, but would not be an easy fit on a timeline. Rather, it would provide a context that might *interact* with, or perhaps *supersede*, any effect from the intervention.

Finally, the evaluator must be attuned to potential unknown confounders. These, however, may only be treatable through the use of statistical approaches (e.g., propensity score matching) that create statistical, pseudo comparison groups/factors for the analysis.

When using a nonexperimental counterfactual approach, the identification of rival explanatory factors and their treatment in the analysis is critically important.[33] Table II.2-3 is an example aid for use in soliciting opinion from nonparticipant experts about what DOE/EERE contributed as compared with other organizations. Walking these experts through Table II.2-3 or a similar device may assist them in preparing their responses to interview or survey questions.

[32] Figure II-2 is derived from an actual EERE evaluation study, but presented here for illustrative purposes only.

[33] When a quasi-experimental design has a weak comparison group, it is recommended that, the major rival factors be explicitly treated.



Source: Navigant Consulting, Inc. (2013).

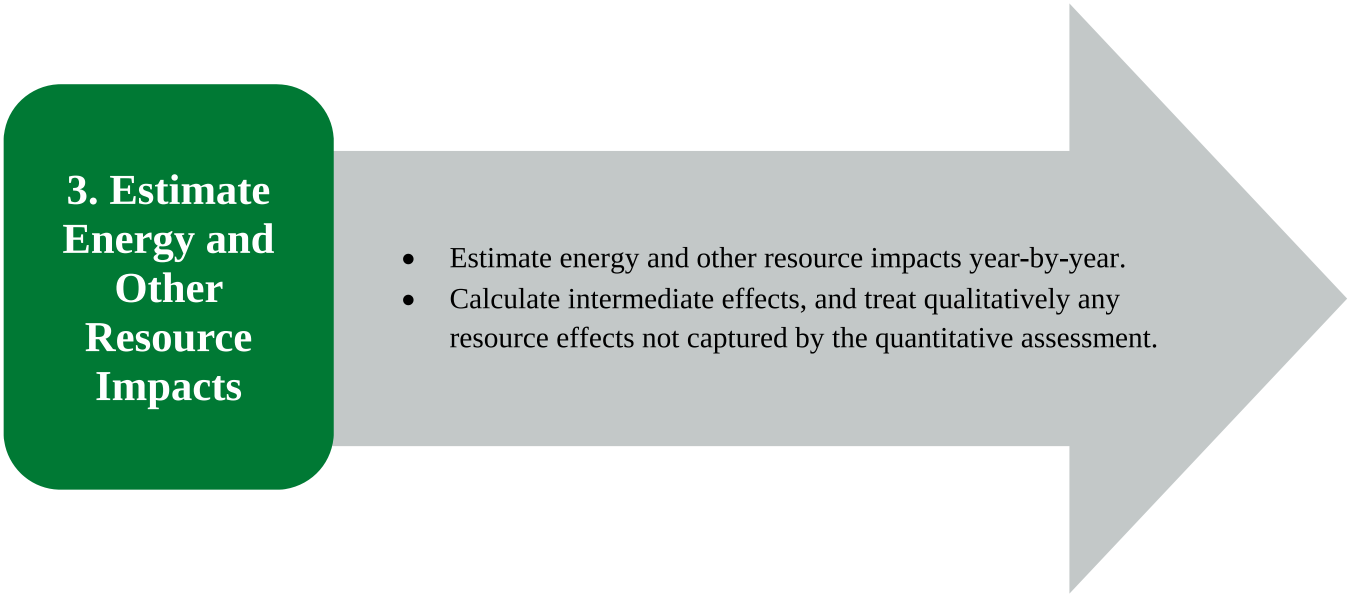
Figure II.2 Example of Timeline of Rival Explanatory Factors, Showing Wind Market Timeline and Capacity Additions for the State of Illinois During the Period Covered by the Wind Powering America Initiative (1999-2010)

Table II.2-3 Example Table to Aid with Identifying Rival Explanatory Factors

Categories of Information Needed for Additionality (Attribution) Assessment	Technology to Early Market Timeline →					
	Integrating, accelerating activities	Develop components, systems	Validate/ demonstrate, Commer-cialize	Manufacture, Supply (in U.S.)	Early Market Adoption	Capabilities for Continuing Growth
History of the technology/ market						
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						

Modified from Ruegg and Jordan, 2011.

II.3 Estimate Energy and Other Resource Impacts



Step 3 guides the estimation of energy and other resource impacts resulting from end use of the technologies selected for detailed analysis. This step proceeds through two sub-steps (3.A and 3.B), with emphasis on determining how the selected technologies affect the consumption of resources—energy, labor, capital, and materials— and how to estimate impacts that have resulted from the EERE investment.

3.A Estimate energy and other resource impacts year-by-year

This sub-step comprises six tasks:

1. Assemble data and develop a taxonomy.
2. Take into account whether EERE's effect is primarily through R&D or if it also entails market promotion strategies.
3. Take into account import and export effects as needed.
4. Estimate energy savings or capacity added in physical units by energy type, taking into account the next-best technology and additionality.
5. Estimate other resource impacts in physical units, taking into account the next-best technology and additionality.
6. Estimate the resulting year-by-year dollars of savings for all resource categories, showing, where a breakout is possible, results before additionality is taken into account and after.[34]

3.A.1 Assemble data

Apart from data collected during interviews, time series data used in the economic analysis should come from U.S. government statistical sources, where available, such as the Energy Information Administration, Bureau of Labor Statistics, Bureau of Economic Analysis, or the U.S. Census

[34] When the next-best alternative is defined as the same technology in a scenario without the EERE investment, generally there will be no benefits absent EERE to report (e.g., the solar photovoltaic evaluation, O'Connor et al., 2010, and the advanced combustion evaluation, Link, 2008). In contrast, when the next-best alternative is defined separately from the EERE intervention, generally there will be benefits without EERE and a share of those benefits that are considered the result of the EERE investment (e.g., the geothermal evaluation, Gallaher et al., 2010).

Bureau. If required data are unavailable from federal surveys, data from nongovernmental organizations, such as trade associations, professional associations, universities, and private entities may be used provided their use has been previously accepted, as evidenced by use in quality peer-reviewed publications and EERE assessments. For example, materials prices or technology-specific technical and economic performance characteristics may not be captured by federal surveys and only be available from such organizations.

The exception is data that comes from interviews (unpublished), such as, for example, a time series of profit data constructed based on profit margins.

It may be useful to also relate the physical change metric or the economic value of the metric to metrics that are commonly reviewed by EERE analysts. For example, although an analysis may explore production cost per watt, it would be helpful to EERE renewable energy technology offices to discuss the implications of this metric for Levelized Cost of Energy (LCOE). The evaluator should review the metrics used by the technology office and discuss how the metrics used by the analysis relate to the metrics used by EERE staff.

The use of rules of thumb (e.g., 5-year assumed acceleration) is unacceptable. Rules of thumb are often simplifying assumptions, which can introduce calculation errors. For example, a 2001 study used a fixed 5-year acceleration assumption for all technologies it examined. However, recent counterfactual-based studies of EERE technologies have shown empirically-derived accelerations of 2, 6, and 12 years, depending on the technology. Using a fixed rule of thumb in a R&D impact analysis risks adding unacceptable uncertainty to the accuracy of calculated returns and other impacts.

3.A.2 Take into account whether EERE's effect is primarily through R&D or if there are also market adoption strategies

There is a strong symbiotic relationship between technology R&D programs and demand side policies. Indeed, these are complementary tools that policymakers use to catalyze technological and market solutions deemed to be in society's best interest. Whereas R&D initiatives spur technological progress, demand side policies stimulate technology adoption. It is possible for a technology's progress (e.g., efficiency, cost) to be accelerated by some number of years but for there to be negligible changes in the demand for that product. However, a tax credit, for example, could stimulate demand for the product. Yet, the tax credit may not have been enacted if technological progress had not been promising.

Most EERE R&D investments have their impacts mainly on the supply side—reducing production costs and increasing performance. The objective of the EERE evaluation in this case is to quantify the returns to R&D for each product unit installed or in operation. Demand side policies should be left unchanged.

Therefore, collect impact data based on changes in cost/price *or* quantity from experts and program participants. Without having specific information on relevant elasticities, interviewed company participants and industry experts should not be expected to reason through simultaneous changes in quantity and price/cost. If annual quantity demanded is to be left unchanged, interviewees should be instructed that when providing impact estimates in terms of cost reductions, cost reductions from returns to scale remain as observed. In this case, interviewees should be asked to provide estimates of cost changes influenced only by R&D.

However, in the case of an EERE R&D and deployment program, EERE is directly supporting both technology development and market adoption. In these cases, not only can EERE claim economic benefits for technological progress, but also for market facilitation activities that serve to increase the number of installations or units in use. The evaluator is not only quantifying the returns to technological progress (e.g., changes in efficiency, productivity) but the entire returns associated with the combined R&D and deployment investments. In this case, estimates likely will be needed both for changes in costs and performance, but also in quantity.

3.A.3 Take into account import and export effects as needed

The following items apply to treating imports and exports in EERE evaluations:

- For U.S. exports, estimation of producer surplus is acceptable; however the consumer surplus must be ignored as it accrues to a non-U.S. stakeholder.
- For U.S. imports, estimation of producer surplus is acceptable for U.S. firms' overseas production. Such imports can be treated in the same manner as domestically-produced, domestically-consumed installations.
- For U.S. imports of foreign firm production, where there is sufficient evidence of EERE influence, estimation of consumer surplus is acceptable but the estimation of producer surplus is not.

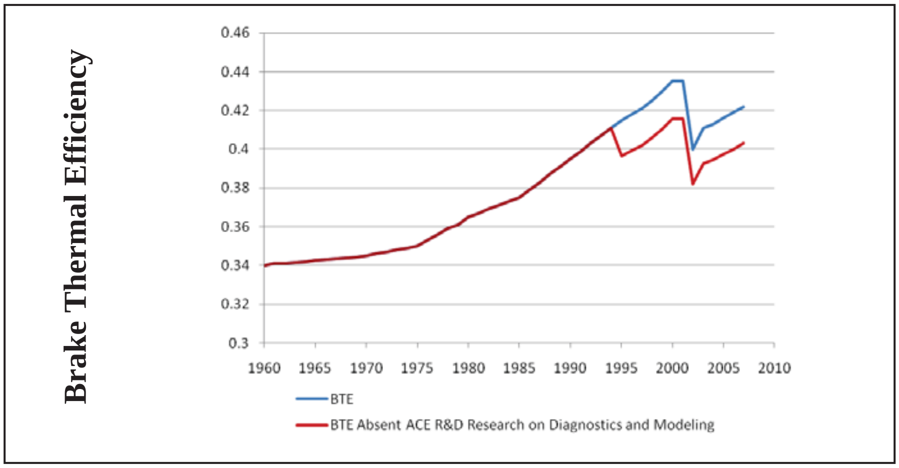
Thus, for exports, the capture of rents from non-U.S. parties and the cost savings associated with any production changes are calculable as benefits. Changes in environmental emissions, energy security, or other benefits are not calculable as they accrue to non-U.S. parties. Imports from non-U.S. firms can be included in environmental and energy security benefits estimation if there is a scenario under which non-U.S. firms' product offerings were accelerated in direct response to competitive pressures from U.S. firms, where results are adjusted to reflect the extent of acceleration resulting from EERE investment. U.S. subsidiaries of international firms can be treated as domestic firms in this analysis if they received EERE funding.

3.A.4 Estimate energy savings or capacity added in physical units by energy type, taking into account the next-best alternative and additionality

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 fully documented in the study report.

The following example illustrates the calculation of fuel savings in the Advanced Combustion Engine (ACE) R&D Benefit-Cost Study, where billions of gallons of diesel fuel were saved. (See the background in the highlighted box below and then Figure II.3-1.)

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-2-1 (expert-derived counterfactual BTE). The change in MPG was statistically estimated (∂MPG / ∂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.



Source: Link (2010).

Figure II.3-1 Comparing Actual and Counterfactual BTE

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 impacts—environmental and energy security impacts. (Note that the quantity changes in fossil fuel consumption by type estimated here are carried forward to Steps 4 and 5.) Thus, all energy effects by type and physical quantity should be broken out for separate treatment.

The best metric(s) for quantifying resource effects is that which is closest to the goal of the technology. For the solar photovoltaic evaluation, for example, it was change in production cost per watt. For the combustion efficiency evaluation, it was change in break thermal efficiency. These metrics best captured the objective of the R&D for these two particular technology assessments.

An illustration of estimating an energy impact is provided in Table II.3-1 from the geothermal benefit-cost study (Gallaher et al., 2010). The table shows the estimation of energy resulting from productivity gains attributed to the Geothermal Technologies Office due to its contributions to development of reservoir models. Benefits of the new reservoir models in comparison with the next-best alternative are given, as well as that part of these benefits estimated to result from the EERE investment.

An illustration of resource savings from using PDC Drill Bits is illustrated in Figure II.3-2 (Gallaher et al. 2010). A main advantage of PDC drill bits over the conventional roller cone bits is that they allow higher rates of penetration, reducing the time that expensive drill rigs must be rented. Oil well footage drilled, percentage of well footage drilled with PDC bits, and average savings per foot drilled were inputs to the calculated savings shown in Figure II.3-2.

Finally, data appearing in report tables may be independently rounded to reflect the desired number of significant digits; however, rounded values may not be used in any intermediate calculations, because it becomes difficult to replicate results electronically.

3.A.5 Estimate other resource impacts in physical units

Also compile changes in other resources in physical units. Use the collected data to perform year-by-year comparisons of the selected technology or group of technologies against the appropriate next-best alternative to derive the differences in the other types of affected resources stated in physical units. For example, what are the effects on labor requirements? What are the differences in purchase, installation, and maintenance costs? What are the differences in reliability? These effects, like energy, may differ among the selected technologies or groups of technologies and, if so, will require separate, individual comparisons of each technology or group of technologies with its respective next-best alternative.

3.A.6 Estimate resulting year-by-year dollars of savings for all resource categories

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. Include the effects of all affected resources—including energy, labor, and capital. If the estimates are in actual (current) dollars, convert from current to constant terms. The conversion from current to constant dollars is done using Gross Domestic Product (GDP) Implicit Price Deflators from U.S. Department of Commerce's Bureau of Economic Analysis (BEA). These price deflators are routinely updated by BEA, and to prevent variations among the benefit-cost studies merely from using different price deflator series, this Guide prescribes the use of the same series of price deflators to be used by all studies conducted within a funding cycle. See also Step 7.

Show valued in dollars the calculated year-by-year resource benefits in tabular form for each separately treated technology or group of technologies within a portfolio, as well as for each type of economic benefit. Show the sum of constant dollar cash flows as undiscounted economic benefits. Where there is a clear separation of the estimation of benefits prior to and after the additionality analysis, report the results separately.

Repeat the above tabular treatment for each separately treated technology or group of technologies within the portfolio. 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 of resource impacts that brings together the year-by-year constant dollar cash flows of energy impacts from 3.A.4 and other resource impacts, such as those for labor cash, for each technology or group of technologies within a portfolio.

3.B Calculate intermediate effects, and treat qualitatively any resource effects not captured by the quantitative assessment

This sub-step completes Step 3. It entails two tasks. The first is to record intermediate effects. The second is to assess whether there are any resource effects that were not captured by the quantitative assessment, and, if so, treat them qualitatively.

3.B.1 Analyze intermediate results metrics

Various stakeholders have an interest in several of the intermediate metrics of benefit-cost studies, in addition to the final outcome metrics. Intermediate metrics are those that can be derived as part of the analytics of calculating the final outcome type metrics.

Economic analyses can be performed using software packages or programming languages that best suit the evaluator and evaluation; however, data, calculations, and results must be available in spreadsheet format in order to provide one of the required deliverables. Also, the analysis must be fully replicable from tables, figures, formulae, and text presented in the report, and readers will expect to be able to follow all calculations.

For example, in the solar photovoltaic analysis (O'Connor et al., 2010), figures were drawn that showed how technology development forced down the production cost per watt, all else held equal. Figure II.3-3 below shows the acceleration effect of EERE's Solar photovoltaic R&D. In the absence of EERE partnership funding, technical expertise, and technology infrastructure, industry progress would have proceeded at a slower pace. The acceleration effect due to EERE R&D is estimated to be 12 years, on average. As shown in Figure II.3-3, solar photovoltaic module production cost per watt, as a result of EERE R&D, was $8.16 in 1988 instead of reaching that cost in 2000 had there been no EERE R&D.

3.B.2 Treat qualitatively any resource effects of the technologies selected for detailed analysis not quantitatively captured

As noted in Section I.2.3, not all resource effects can be quantified either in monetary terms or in physical units. If there are resource effects for the selected technologies that cannot feasibly be quantified in monetary or physical units, describe those effects qualitatively.

Table II.3-1 Example from the Geothermal Benefit-Cost Study 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						
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		10,884,950	1,088,495	$93,066	$21,405
1999	$83.0		10,938,045	1,093,805	$90,786	$20,881

(Continued)

2000	$83.3		10,204,190	1,020,419	$85,001	$19,550
2001	$87.2		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, Undis-counted						$548,675

Gallaher et al, 2010.
Notes: Cols 2 and 3 sourced from Energy Information Administration (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 the Table for greater ease in exposition, but they are included in the benefit-cost study by Gallaher et al. (2010).
Resource benefit cash flows are shown both before and after the estimation of additionality (which is called "attribution" in the table).

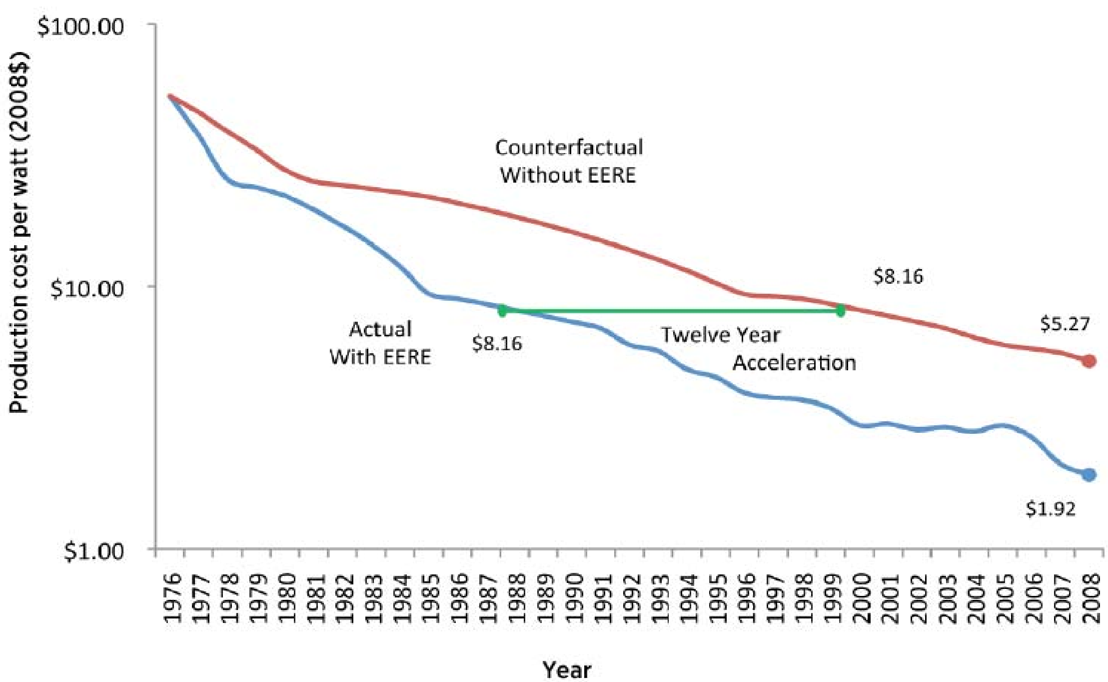


Figure II.3-2 Actual and Counterfactual Solar Photovoltaic Module Production Cost

Table II.3-2 Example from the Geothermal Benefit-Cost Study Showing the Estimation of Drill Rig Rental Savings from Use of PDC Drill Bit Technology

Year	Crude Oil Well Footage Drilled with PDC Bits	Savings Based on Wells' Footage (Thousand $2008)
1982	5,450,440	$467,911
1983	7,584,720	$651,136
1984	12,028,720	$1,032,646
1985	12,787,400	$1,097,777
1986	8,148,536	$699,538
1987	8,013,192	$687,919
1988	7,896,244	$677,880
1989	6,495,548	$557,632
1990	9,152,820	$785,755
1991	9,663,764	$829,618
1992	8,156,540	$700,226
1993	8,300,148	$712,554
1994	7,115,144	$610,823
1995	7,815,280	$670,929
1996	9,066,535	$778,347
1997	12,005,000	$1,030,610
1998	7,997,250	$686,551
1999	4,444,750	$381,574
2000	7,958,000	$683,181
2001	11,795,225	$1,012,601
2002	10,504,000	$901,751
2003	14,823,000	$1,272,530
2004	16,867,000	$1,448,004
2005	23,271,600	$1,997,829
2006	33,625,200	$2,886,668
2007	44,910,000	$3,855,450
2008	48,893,400	$4,197,418
Total		**$31,314,860**

Gallaher et al., 2010.

II.4 Estimate Environmental Impacts

4. Estimate Environmental Impacts

- Estimate changes in air pollution emissions.
- Estimate avoided adverse health events and environmental health benefits using COBRA.
- Estimate the value of changes in GHG emissions using the social cost of carbon.
- Describe other notable environmental effects.

This section describes how to estimate environmental impacts, particularly changes in air pollution emissions, changes in the incidence of adverse health events (and their economic value), and the economic value of changes in GHG emissions. It also explains how to account for other notable environmental benefits.

4.A Estimate changes in air pollution emissions

The estimation of environmental benefits likely began in Step 3 with the determination of changes in energy consumption by fuel type (i.e., coal, natural gas, oil). Bring forward to Step 4 any year-by-year changes in energy expressed in physical units, and estimate the corresponding air emission changes.

Estimate changes in GHGs, including carbon dioxide (CO_2), methane, and nitrous oxide, for example. Estimate emissions changes by GHG and convert to CO_2 equivalents using the factors listed in Table II.4-1. Report changes in GHG emissions in terms of CO_2 equivalents based on individual GHGs' 100 year global warming potential, as estimated by the Intergovernmental Panel on Climate Change (IPCC) (1995).

Also estimate emission changes for other air pollutants, including particulate matter ($PM_{2.5}$), carbon monoxide, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs), as appropriate.

Refer to emissions changes associated with reduced fuel combustion estimated in Step 3 as "avoided emissions" and those associated with increased fuel combustion as "increased emissions." This section assumes that evaluations will normally deal with reduced fuel consumption and, hereafter, will use the term "avoided emissions."

Table II.4-1 100 Year Global Warming Potentials of Greenhouse Gases Used for National Inventory Reporting

Name	Chemical Formula	100 Year Global Warming Potential (CO_2 equivalent Conversion Factor)
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Sulfur hexafluoride	SF_6	23,900
HFC-23	CHF_3	11,700
HFC-32	CH_2F_2	650
HFC-125	CHF_2CF_3	2,800
HFC-134a	CH_2FCF_3	1,300
HFC-143a	CH_3CF_3	3,800
HFC-152a	CH_3CHF_2	140
HFC-227ea	CF_3CHFCF_3	2,900
HFC-236fa	$CF_3CH_2CF_3$	6,300
PFC-14	CF_4	6,500
PFC-116	C_2F_6	9,200
Perfluoropropane	C_3F_8	7,000
Octafluorocyclobutane	c-C_4F_8	8,700
Perfluorobutane	C_4F_{10}	7,000
Perfluoropentane	C_5F_{12}	7,500
Perfluorohexane	C_6F_{14}	7,400

Note: Global warming potentials are consistent with international reporting guidelines. Greenhouse gases that are short-lived and vary regionally such as black carbon and water vapor, are not included in national inventories and need not be treated in the evaluation. Source: Intergovernmental Panel on Climate Change (IPCC) (1995); Second Assessment Report.

If changes in energy generation estimated in Step 3 are not directly associated with a fuel source, the evaluator must make appropriate assumptions for what fuel sources are affected. A simplifying assumption for technologies that displace electricity consumption would be to assume displacement of the average fuel source per MWh based on data from the Energy Information Administration (EIA). If state-level results are available, the estimates of fuel sources displaced should be refined using the energy mix by state. See, for example, the estimate of avoided fuel consumption for electricity generation in the solar photovoltaic evaluation study prepared by O'Connor et al. (2010; Chapter 6).

For renewable energy topics, more detailed analyses may be needed to capture the differential displacement of peaking and base units depending on the expected timing of energy generation or savings. For example, geothermal would be considered base load, but solar is akin to peaking units because of the timing of these resources.

Estimating changes in emissions from changes in fuel consumption requires the use of emission factors.[35] Where the relevant emissions factors are technology-specific, such as an all-electric vehicle or a conventional gasoline vehicle, use the appropriate technology-specific emissions factors. Stationary point and area source emissions factors are available using the EPA WebFIRE.[36] Mobile source emissions factors are available from the EPA Office of Transportation and Air Quality.[37]

If the relevant emissions factor is for a sector, such as for coal-fired electricity generation, use EPA's National Emissions Inventory (NEI). NEI data in 2008 provides county-level emissions estimates at a detailed sector level.[38] These total emissions must be converted to a per unit emissions factor using relevant usage data, such as electricity generated based on EIA estimates. In addition to the detailed data in 2008, national emissions estimates by Tier 1 sector are available from 1970 to 2012 and national emissions by Tier 3 sector from 1970 to 1998.[39] For GHGs, evaluators should use emissions factors used by EPA's Center for Corporate Climate Leadership.[40] Use linear interpolation to estimate data for any missing years.

4.B Estimate avoided adverse health events and environmental health benefits using COBRA

EPA's Co-Benefits Risk Assessment (COBRA) model has been adopted by the Guide to provide first-order estimates of avoided adverse health events and their economic value, termed environmental health benefits, resulting from avoided air emissions. COBRA is a user friendly tool designed to be methodologically consistent with EPA's Environmental Benefits Mapping and Analysis Program (BenMAP), which is a detailed set of modeling tools used by EPA for regulatory analysis, such as for the Regulatory Impact Analysis of the Final Mercury and Air Toxics Standards (U.S. EPA, 2011).[41] Use of COBRA enables the health impact functions and the unit economic values used in EERE benefit-cost studies to be consistent with EPA analyses.

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[35] 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 of emissions per MWh of electricity produced from different fuel types including natural gas, coal, oil, nuclear energy, municipal solid waste, hydropower, and a variety of renewable energy sources.

[36] The Factor Information Retrieval System is available online at http://www.epa.gov/ttn/chief/webfire/index.html.

[37] Available at http://www.epa.gov/otaq/models.htm .

[38] Available at http://www.epa.gov/ttn/chief/net/2008inventory.html.

[39] Available at http://www.epa.gov/ttn/chief/trends/index.html.

[40] Available at http://www.epa.gov/climateleadership/inventory/ghg-emissions.html.

[41] For a detailed discussion of studies used for health impact functions and unit values, see EPA (2011, December). Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards. EPA-452/R-11-011. Research Triangle Park, NC: Office of Air Quality Planning and Standards; Health and Environmental Impacts Division. Available at http://www.epa.gov/ttnecas1/regdata/RIAs/matsriafinal.pdf

COBRA version 2.4[42], released in 2012, estimates the health impact of air quality changes for 2017 based on projected changes in air quality, national income, and population growth. At the core of the COBRA model is a county-level source-receptor (S-R) matrix that translates changes in emissions to changes in $PM_{2.5}$ concentrations. The changes in ambient $PM_{2.5}$ concentrations are then linked to changes in mortality risk and changes in health incidents that lead to healthcare costs and/or lost workdays. Figure II.4-1 provides an overview of the modeling steps. With some minor adjustments, COBRA can provide retrospective estimates, although those estimates will be conservative because the COBRA will assume that regulations in place as of 2017 will also be in place in earlier years.[43] As EPA makes improvements to their modeling of air quality health impacts in BenMAP, these changes are expected to be reflected in future versions of COBRA.

COBRA supports selection of air pollutants by type. The annual changes in emissions 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 "nationwide" 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 by region for the year 2017.

In addition to entering changes in emissions, the user identifies the sector in which the emissions are reduced. For example, the sector is light-duty gas vehicles in the case of the evaluation study of NiMH and Li-ion Energy Storage by Link et al. (2013). The specified 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.4-2 shows the different health endpoints that are included in the COBRA model.

Two of the health endpoints are valued based on present value calculations that require the specification of a discount rate. Incidents of premature mortality are assumed to occur over 20 years, with 30% of incidents of premature mortality assumed to occur in the analysis year, 50% spread evenly between years 2 and 5, and the remaining 20% between years 6 and 20. Additionally, nonfatal heart attacks are assumed to incur costs for five years following the event. For this reason, the value estimates for these health endpoints vary based on the discount rate used. The evaluator should include results with both a 7% and 3% discount rate consistent with the other cost and benefit estimates. COBRA must be run for each discount rate for each year.

COBRA translates the health effects into changes in monetary impacts using per-unit

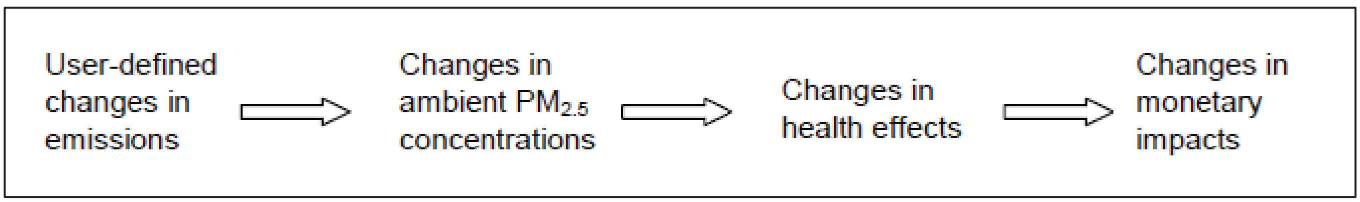
[42] The COBRA Model is available on request from EPA, in the form of downloadable software and a user manual (EPA User's manual for the Co-Benefits Risk Assessment (COBRA) screening model. Version: 2.4 October 2012).

[43] COBRA is expected to provide a conservative estimate of the health benefits of reducing emissions for the following reasons: COBRA does not include the effects of many pollutants that may negatively affect health, and COBRA does not fully capture the economic value of health events 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.

monetary values in 2010 dollars (2010$) described in the COBRA user's manual. (evaluators need to convert from the 2010$ values to the appropriate dollar year using the BEA GDP deflator, consistent with the rest of the analysis.)

Because COBRA is calibrated to a 2017 baseline, two adjustments must be made to COBRA results after the simulation runs—population adjustment and income adjustment.

First, the ratio of retrospective population estimates to COBRA's 2017 projected population should be used to scale health outcomes. This scaling will adjust for overall magnitude changes; however, it will not adjust for how demographic shifts influenced the estimated health impacts. For nationwide analyses, evaluators should use intercensal estimates of the resident U.S. population up to 2010. After 2010, evaluators should use estimates of the resident U.S. population as of July 1st for each year until intercensal estimates are available following the 2020 census.



Source: U.S. EPA. 2012c. *User's manual for the Co-Benefits Risk Assessment (COBRA) screening model. Version: 2.4.* October 2012.

Figure II.4-1 COBRA Model Overview

Where evaluations consider remaining effective useful life (EUL) impacts[44] of retrospectively adopted technology in future years, populations should be projected forward based on the percentage change in U.S. population projections in the most recent Annual Energy Outlook (AEO). Using the percentage change from the AEO is necessary to ensure that all calculations and adjustments within COBRA remain internally consistent and without unintended discontinuities.

The 2017 population estimate for the continental U.S. in BenMAP is 315,761,800. To compare to the U.S. Census population estimates, this value first needs to be adjusted to reflect a projected population estimate including Hawaii and Alaska. For example, using the fraction of the U.S. population in Hawaii and Alaska in the 2010 Census, the corresponding total U.S. resident population based on the 2017 BenMAP value would be 317,893,682.

[44] EUL is treated in Step 8.

Table II.4-2 Health Endpoints Included in COBRA

Health Effect	Description/Units
Mortality	Number of adult deaths
Infant Mortality	Number of infant deaths
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
Asthma exacerbations	Number of episodes with cough, shortness of breath, wheeze, and upper respiratory symptoms in asthmatic children

Source: U.S. EPA. 2012c. *User's manual for the Co-Benefits Risk Assessment (COBRA) screening model. Version: 2.4.* October 2012.

Second, several valuation endpoints in COBRA, including the value placed on premature mortality, are adjusted over time based on projected changes in income and elasticity estimates for how willingness-to-pay for health outcomes change with income. For the retrospective part of the analyses, evaluators should estimate the adjustment factor based on observed per capita real GDP changes over time. The ratio of the retrospective adjustment factors to COBRA's 2017 adjustment factor can be used to scale the valuation of health outcomes. Where evaluations consider remaining EUL impacts of retrospectively adopted technology in future years, per capita real GDP should be projected forward for the future years based on the percentage change in per capita real GDP projections in the most recent AEO.

Table II.4.3 shows the formulas used to adjust 2017 COBRA results to the appropriate year.

The changes in adverse health events and the equivalent monetary value are derived using the formulations in Table II.4-3.

COBRA produces both a low and a high result to represent a range of estimates for premature mortality and nonfatal heart attacks based on mortality literature. Carry forward the mean of the low and high estimates to Step 7 to calculate economic performance measures.

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Table II.4-3 Calculating Appropriate Year Values from COBRA 2017 Results

Measure	Formulation
Health Incidents	An adjustment to the avoided health incidents estimated in 2017 to account for changing population. $H_{i,y} = H_{i,2017} \times PopAdj_y$ where $H_{i,y}$= number of avoided health incidents of type *i* in year *y*. $H_{i,2017}$ = number of avoided health incidents of type *i* reported by COBRA for the year 2017. $PopAdj_y$= population adjustment factor for year *y*.
Valued Health Incidents	An adjustment to the values of avoided health incidents estimated in 2017 to account for price changes and changing income. $TotalVal_y = (DeflatorAdj \times PopAdj_y)(MortVal_{2017} \times MortAdj_y + MinorVal_{2017} \times MinorAdj_y + OtherVal_{2017})$ where $TotalVal_y$= value of avoided health impacts in year *y*. $DeflatorAdj$ = price deflator to adjust values from $2010. $PopAdj_y$= population adjustment factor for year *y*. $MortVal_{2017}$= value of avoided mortality reported by COBRA for the year 2017. $MortAdj_y$= income adjustment factor for mortality impacts in year *y*. $MinorVal_{2017}$= value of avoided minor health impacts reported by COBRA for the year 2017. $MinorAdj_y$= income adjustment factor for minor health impacts in year *y*. $OtherVal_{2017}$= value of other health impacts reported by COBRA for the year 2017.

Evaluators should show in tables, first, the detailed year-by-year mortality and morbidity data and associated monetary values, and the totals over the analysis period, using the 7% discount rate; and, second, the year-by-year environmental health benefits based on the 7% discount rate, footnoted to indicate that each year's value has discounting internal to the COBRA model. The first table is illustrated by the example in Table II.4-4 produced by application of the COBRA model in the NiMH and Li-ion Energy Storage Evaluation by Link et al. (2013). A separate set of tables could be provided for the 3% discount rate, or additional columns could be added to the tables to provide 7% and 3% results side by side (Table II.4-5)

The year-by-year environmental health benefits at both the 3% and 7% discount rate are carried forward to Step 7, and used in the bottom-line economic performance measures. Using COBRA to estimate health benefits in dollar terms provides sufficiently credible monetary estimates to warrant the approach of carrying the estimates forward and combining them with energy and other resource benefits in a Level 2 analysis, as well as with social cost of carbon estimates in a Level 3 analysis of overall measures of economic performance (e.g., net present value benefits, benefit-to-cost ratios, and internal rate of return) in Step 7.

When calculating performance measures in Step 7, the corresponding COBRA results should be used when estimating net present values and benefit-to-cost ratios. Use the 7% COBRA results when calculating
.

Table II.4-4 Illustration of Health Benefit Calculations Results from the COBRA Model, Year 2012, Using a 7% Discount Rate

Health Effect	Avoided Incidence	Benefit (thousands of 2012$)
Adult mortality	2.3 – 6.0	$17,348 - $44,589
Infant mortality	0.0[a]	$43
Nonfatal heart attacks	0.3 – 2.6	$34 - $316
Resp. hospital admissions	0.9	$26
Cardio-vascular (CDV) hospital admissions	0.8	$34
Acute bronchitis	3.8	$2
Upper respiratory symptoms	68.4	$5
Lower respiratory symptoms	47.9	$2
Asthma ER visits	1.6	$1
Minor restricted activity days (MRAD)	2,114.6	$147
Work loss days	357.3	$56
Asthma exacerbations	71.9	$8
Total health costs (2012$)		$17,706 to $45,229

Source: COBRA model results from Link et al. (2013).

performance measures with the 7% discount rate, and use the 3% COBRA results when calculating performance measures with the 3% discount rate. This is necessary because COBRA generates values using internal user-specified discount rates.

Evaluators should be aware of how COBRA may affect the calculation of the IRR performance measure for Level 2 and higher. When estimating the IRR, evaluators should use the time series of values discounted at 7% with the understanding that there may be some slight bias to the overall internal rate of return. COBRA results are exogenous. Therefore, when calculating the IRR results are not being iterated as the solution rate is sought. Since the values remain generated at a 7% discount rate, the internal rate of return on the stream of total net benefits will be slightly biased.

4.C Estimate the dollar value of avoided GHG emissions using the social cost of carbon

To estimate the dollar value associated with avoiding a metric ton of GHG emissions, an intergovernmental working group has developed estimates of the social cost of carbon (SCC) (Interagency Working Group [IWG] on Social Cost of Carbon, 2013). The values are based on results from three

Integrated Assessment Models (IAMs) of how GHGs released in 2010, 2020, 2030, 2040 and 2050 will influence global economic output over a multi-century timescale. See Figure II.4-2.

Table II.4-5 Pump-to-Wheel Time Series of Environmental Health Benefits, 1999–2022 (Thousands of 2012$ Using 7% Discount Rate)

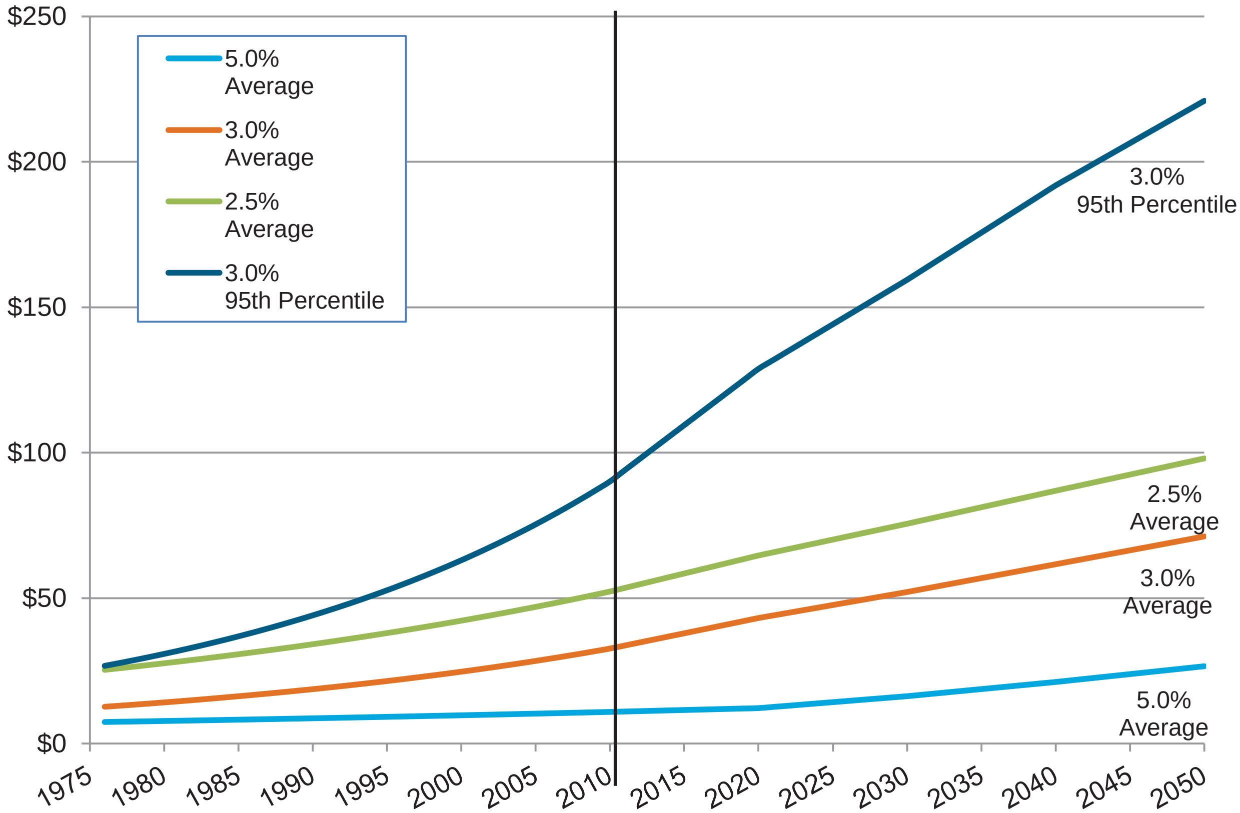
Year	(1) Miles Driven (in thousands)	(2) U.S. Resident Population[a] (in thousands)	(3) Environmental Health Benefits (low)[b]	(4) Environmental Health Benefits (high)[b]
1999	97	279,040	$0	$0
2000	58,895	282,162	$68	$174
2001	195,901	284,969	$229	$584
2002	449,485	287,625	$531	$1,357
2003	788,913	290,108	$946	$2,416
2004	1,393,754	292,805	$1,703	$4,351
2005	2,877,430	295,517	$3,578	$9,140
2006	4,632,866	298,380	$5,548	$14,172
2007	6,918,298	301,231	$8,133	$20,776
2008	8,736,302	304,094	$10,169	$25,975
2009	10,178,950	306,772	$11,684	$29,844
2010	11,337,092	309,326	$13,140	$33,563
2011	12,395,177	311,588	$14,757	$37,695
2012	14,273,723	313,914	$17,706	$45,229
2013	13,689,024	316,969	$17,183	$43,894
2014	12,945,702	320,051	$16,492	$42,129
2015	11,883,232	323,156	$15,349	$39,209
2016	10,418,077	326,283	$13,634	$34,830
2017	8,742,915	329,427	$11,766	$30,057
2018	6,806,933	332,586	$9,475	$24,206
2019	5,213,999	335,758	$7,552	$19,293
2020	3,833,351	338,942	$5,831	$14,896
2021	2,662,274	342,133	$4,289	$10,958
2022	1,368,481	345,328	$2,271	$5,802
1999–2012			$88,192	$225,277
1999–2022			$192,034	$490,552

[a] Source: 1999 through 2012 estimates from U.S. Census Bureau (2004, 2011, 2013). 2013 through 2022 based on percentage changes in population projected in the 2013 Annual Energy Outlook (U.S. Energy Information Administration, 2012).
[b] Values of future health impact have been discounted at 7% in each year.

Multiplying avoided GHG emissions (in CO_2 equivalents) by the SCC provides an estimate of the economic value of the avoided GHG emissions.

SCC estimates were developed specifically to support regulatory impact analysis. EERE evaluations are not regulatory impact analyses, however using SCC values permits inclusion of technologies' GHG avoidance in economic performance measures. Working from information and data provided by the IWG, the co-authors of this Guide estimated the SCC for each year between 1976 and 2010, solely to support EERE benefit-cost evaluations.

There are four SCC values, but for EERE purposes, the 3% average value is the central value that should be reported in the evaluation report summary tables. The 5% average, the 2.5% average, and the 3% 95th percentile case should be used to create a range of estimated values.



Note: 1976 to 2010 values were calculated by RTI International's Ross Loomis, in consultation with the National Center for Environmental Economics at the Environmental Protection Agency. Historical SCC values were generated by RTI specifically for use in EERE retrospective economic impact analyses of EERE-supported energy technology R&D, based on the SCC estimates released in 2013. Methods and results were reviewed by economists with the NCEE to ensure consistency with the IWG results. 2010 through 2050 are from the Interagency Working Group on Social Cost of Carbon (2013).

Figure II.4-2 Social Cost of Carbon by Scenario and Year (2007$)

Due to uncertainty surrounding the appropriate intergenerational discount rate for impacts of GHGs, the first three SCC values—at 5%, 3%, and 2.5%—reflect different intergenerational discount rates for future cost and benefits.[45] A large uncertainty beyond the choice of discount rate is the actual damage that may occur in any given year due to higher GHG emissions. The fourth value is intended to represent some of the uncertainty associated with both temperature change and its impact on the environment on a multi-century scale. This 95th percentile of damages discounted at 3% is intended to reflect the potential for less likely but higher damages associated with GHGs. It may still be conservative given the limited ability of models to estimate damages or properly account for the potential consequences of feedback loop.

Table II.4-6 presents the SCCs by year to be used in retrospective analyses. IWG did not estimate SCCs prior to 2010. EPA's National Center for Environmental Economics recommended estimating previous years using a backcasting approach by applying the growth rate between 2010 and 2020 to prior years.[46] This methodology was recommended because the SCC is not expected to have increased linearly prior to 2010 and the resulting SCC estimates are consistent with alternative nonlinear functional forms that fit the 2010 to 2050 estimated SCCs, such as quadratic or log-linear relationships.

[45] The central intergenerational discount rate used to estimate the SCC, 3%, was chosen by the IWG to reflect the impacts of GHGs consistent with losses of future consumption. The high intergenerational discount rate, 5%, was chosen to reflect a post-tax 7% discount rate. The low value of 2.5% was chosen as a certainty-equivalent rate to reflect that interest rates are uncertain over time (Interagency Working Group on Social Cost of Carbon, 2010).

[46] U.S. Environmental Protection Agency, personal communication, August 13, 2013.

Given the uncertainty associated with SCC values, the dollar valuation of GHGs is included only in the Level 3 analysis of Step 7.

For the 7% benefit cost analysis results, use the 3% average SCC value and discount these values at 3%, and include a footnote that the use of 3% instead of 7% is to account for intergenerational effects, per the IWG and to be consistent with DOE conservation standards. This footnote must accompany the BCR and the NPV. For the 3% results, use the 3% average SCC value. Evaluators need to convert from the 2007$ SCC values to the appropriate dollar year using the BEA GDP deflator, consistent with the rest of the analysis.

4.D Describe other notable environmental effects

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

The EPA provides information by generating source (e.g., natural gas, coal, oil, municipal solid waste, biomass, land-fill gas, nuclear energy, hydropower, wind, geothermal, and solar) on the differential effects the generating sources have on water, water discharges, land resource use, and solid waste generation.[47]

[47] 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?"

Measure	Formulation
Value of Avoided Greenhouse Gas Emissions	Multiply the social cost of carbon by avoided greenhouse gas emissions and sum over all years while discounting to the initial year in the analysis. $GHGVal_s = \sum_{y=1}^{N} SCC_{s,y} CO_2eq_y/(1+d_s)^y$ where $GHGVal_s$= value of avoided greenhouse gas emissions for social cost of carbon scenario s. $SCC_{s,y}$ = social cost of carbon in year y and scenario s. CO_2eq_y= avoided greenhouse gas emissions in year y reported in CO_2eq. d_s=discount rate used in scenario$s$.

Table II.4-6 Social Cost of Carbon by Scenario and Year, per Metric Ton of CO_2 equivalent (2007$)

Year	5.0% Average	3.0% Average	2.5% Average	3.0% 95th Percentile
1976	7	13	25	27
1977	8	13	26	28
1978	8	13	26	29
1979	8	14	27	30
1980	8	14	28	31
1981	8	15	28	32
1982	8	15	29	33
1983	8	15	29	34
1984	8	16	30	36
1985	8	16	31	37
1986	8	17	31	38
1987	8	17	32	40
1988	8	18	33	41
1989	9	18	33	43
1990	9	19	34	44
1991	9	19	35	46
1992	9	20	36	47
1993	9	20	36	49
1994	9	21	37	51
1995	9	21	38	53
1996	9	22	39	55
1997	9	23	40	57

(Continued)

1998	10	23	40	59
1999	10	24	41	61
2000	10	25	42	63
2001	10	25	43	65
2002	10	26	44	68
2003	10	27	45	70
2004	10	28	46	73
2005	10	28	47	75
2006	10	29	48	78
2007	11	30	49	81
2008	11	31	50	84
2009	11	32	51	87
2010	11	33	52	90
2011	11	34	54	94
2012	11	35	55	98
2013	11	36	56	102
2014	11	37	57	106
2015	12	38	58	109
2016	12	39	60	113
2017	12	40	61	117
2018	12	41	62	121
2019	12	42	63	125
2020	12	43	65	129
2021	13	44	66	132
2022	13	45	67	135
2023	13	46	68	138
2024	14	47	69	141
2025	14	48	70	144
2026	15	49	71	147
2027	15	49	72	150
2028	15	50	73	153
2029	16	51	74	156
2030	16	52	76	159
2031	17	53	77	163
2032	17	54	78	166
2033	18	55	79	169
2034	18	56	80	172
2035	19	57	81	176
2036	19	58	82	179
2037	20	59	84	182
2038	20	60	85	185
2039	21	61	86	189

(Continued)

2040	21	62	87	192
2041	22	63	88	195
2042	22	64	89	198
2043	23	65	90	201
2044	23	65	91	204
2045	24	66	92	206
2046	24	67	94	209
2047	25	68	95	212
2048	25	69	96	215
2049	26	70	97	218
2050	27	71	98	221

Note: 1976 to 2010 values were calculated by RTI International's Ross Loomis, in consultation with the National Center for Environmental Economics at the Environmental Protection Agency. These values may be used for nonregulatory purposes only. 2010 through 2050 are from the Interagency Working Group on Social Cost of Carbon (2013).

II.5 Estimate Energy Security Impacts

5. Estimate Energy Security Impacts

- Bring forward from Step 3 the estimated net reduction in oil consumption in physical units.
- Report in physical units the reductions in barrels of oil consumed and imported.
- Describe notable effects of the portfolio technologies on the nation's energy infrastructure.

The energy security impacts take into account the following components:

- Reduction in oil consumed as fuel, and the proportion of that consumption that would have been imported.
- Qualitative treatment of altered threats to the energy infrastructure.

Report energy security benefits from reductions in oil consumption and imports in physical units only; do not estimate the monetary value using an energy security premium. Do not estimate barrels of oil equivalents for reduction in the consumption of nonpetroleum forms of fossil fuel.

5.A Bring forward from Step 3 the estimated net reduction in oil consumption in physical units

To estimate the reduction in oil consumption, the evaluator must estimate what portion of the net energy savings from Step 3 came from oil products or to what extent generation of renewable energy displaces generation from oil products. Given that Steps 3 and 4 analyzed the energy and environmental impacts, it is likely that avoided oil consumption effects have already been calculated. If so, bring the data forward to use in Step 5 calculations. If these effects were not calculated in Steps 3 or 4, do so now.

If the net reductions in oil consumption are associated with avoided conventional electricity generation, the evaluator must use EIA data available from the Annual Energy Review (U.S. Energy Information Administration, 2012a) to determine the fraction of avoided conventional electricity that would have been generated from oil products. Future years' data will be available from the EIA when those Annual Energy Reviews are released. For an example of these data current as of 2013, see Column 1 of Table II.5-1.

If changes in electricity use and generation developed in Step 3 were generated at the state-level, the analysis should use the state-level fractions. Otherwise, the national fraction must be used. State-level net electricity generation by fuel type and year is available from 1990 (U.S. Energy Information Administration. 2012b), and previous years can be generated using detailed data.[48]

Next, the evaluator must convert from MWhs of avoided electricity generation from oil products to barrels of oil using a conversion factor of 1.84 MWh/barrel (EIA, 2013b).

To estimate avoided oil importation, apply EIA data on the proportion of internationally sourced fuel to the avoided oil consumption estimates. The assumption is that each marginal barrel of oil consumed is sourced proportionate to total consumption. This assumption must be emphasized in the evaluation report at the point the estimation is made. Column 2 in Table II.5-1 illustrates the percentage of internationally sourced oil from 1976 to 2011. Data for subsequent years become available when the EIA releases its Annual Energy Reviews.

5.B Report in physical units the reductions in barrels of oil consumed and imported

Report the energy security benefits from reductions in oil consumption and imports in physical units (gallons and barrels, respectively) only; do not estimate the monetary value using an energy security premium. Do not estimate barrels of oil equivalents for reduction in the consumption of other forms of fossil fuel.[49]

Avoided oil imports are derived using the formulation in Table II.5-2.

5.C Describe notable effects of the portfolio technologies on the nation's energy infrastructure

In some cases, the technology portfolio 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; and improved backup electric generation and energy storage in vulnerable locations can fortify against natural, accidental, and deliberately caused disruptions. If the portfolio technologies have the potential to affect security of the nation's energy infrastructure, provide a qualitative description of the nature of these effects and provide supporting evidence.

[48] Available online at http://www.eia.gov/electricity/data/eia923/.

[49] While the Guide does not provide for the monetary valuation of energy security effects, some have provided partial estimation. Monetized energy security benefits result from the concept that oil prices are above what they would be under competitive market conditions due to market power exerted by the Organization of the Petroleum Exporting Countries. Prices above their competitive market levels due to market power result in losses of potential GDP as well as transfers of wealth from oil imports. In addition, price shocks from disruptions in oil supply result in short term dislocational losses of GDP (Greene and Leiby, 2006). Monetized energy security benefits of reduced or avoided oil consumption are associated with reducing market failures from existing market power, not market failures due to externalities (National Research Council, 2010). All else held equal, by reducing oil demand in the U.S. through technology programs, the global oil price is reduced and the U.S. economy is less vulnerable to shocks in oil prices. The reduction in imported oil price, referred to as the monopsony component, represents a transfer of wealth between the U.S. and oil exporting countries, not a loss of potential economic output. As such, the monopsony component should not be included in the analysis.

Table II.5-1 Percentage of U.S. Electricity Production from Petroleum Products and Percentage of Net Oil Imports by Year, 1976-2012

Year	Electricity Generated from Petroleum Products as a Percentage of Net Electricity Generation(1)	Net Oil Imports as a Percentage of Total Oil Supplied(2)
1976	15.7%	40.6%
1977	16.9%	46.5%
1978	16.5%	42.5%
1979	13.5%	43.1%
1980	10.8%	37.3%
1981	9.0%	33.6%
1982	6.5%	28.1%
1983	6.3%	28.3%
1984	5.0%	30.0%
1985	4.1%	27.3%
1986	5.5%	33.4%
1987	4.6%	35.5%
1988	5.5%	38.1%
1989	5.6%	41.6%
1990	4.1%	42.2%
1991	3.8%	39.6%
1992	3.1%	40.7%
1993	3.5%	44.2%
1994	3.2%	45.5%
1995	2.1%	44.5%
1996	2.3%	46.4%
1997	2.6%	49.2%
1998	3.5%	51.6%
1999	3.2%	50.8%
2000	2.9%	52.9%
2001	3.3%	55.5%
2002	2.4%	53.4%
2003	3.1%	56.1%
2004	3.0%	58.4%
2005	3.0%	60.3%
2006	1.5%	59.9%

(Continued)

2007	1.5%	58.2%
2008	1.1%	57.0%
2009	0.9%	51.5%
2010	0.9%	49.2%
2011	0.7%	44.9%
2012	0.6%	39.9%

Sources: U.S. Energy Information Administration. 2012a. "Annual Energy Review 2011." http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf; U.S. Energy Information Administration. 2013a. "August 2013 Monthly Energy Review." http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

Table II.5-2 Calculating Avoided Imported Oil

Avoided Oil Imports	Multiply the estimated barrels of avoided petroleum products by the percentage of net oil imports of total oil supplied for each year $OilImport_y = PetProd_y \times NetImp_y$ where $OilImport_y$= estimated avoided imported barrels of oil in year y. $PetProd_y$ = estimated avoided barrels of petroleum products in year y. $NetImp_y$= net oil imports as a percentage of total oil supplied in year y.

II.6 Estimate Knowledge Benefits

6. Estimate Knowledge Benefits

- Construct databases of portfolio patents and publications attributed to EERE, plus other databases needed for comparisons.
- Conduct patent citation analyses.
- Identify notable patents attributed to or linked to EERE.
- Apply additional techniques to assess knowledge benefits as budget permits.

Step 6 guides the estimation of knowledge benefits resulting from EERE R&D expenditures in support of a given portfolio. This step proceeds through five sub-steps (6.A to 6.E), with emphasis on knowledge creation and dissemination signaled by outputs of patents and publications—particularly patents.[50]

6.A Construct database of portfolio patents and publications attributed to EERE, plus other databases needed for comparisons[51]

To perform patent and publication analyses, evaluators will need databases of patents and publications that derive from EERE's portfolio investment. The evaluator should determine if EERE program directors have provided for a careful compilation of these databases, thus relieving the evaluator of the task. Previously completed evaluations have required an additional effort on the part of the evaluator to construct the required databases of patents and publications.

Data sources include EERE Annual Progress Reports of R&D programs, which generally list patents and publications associated with its sponsored research. Data sources also include EERE program and DOE laboratory databases. Patent and publication records are centrally maintained by the DOE Office of Scientific and Technical Information (OSTI). Beyond DOE/EERE databases, patent records are maintained by the U.S. Patent and Trademark Office (PTO), the European Patent Office (EPO), the World Intellectual Property Organization (WIPO), and other country patent offices. Organizations whose R&D has received public funding, such as funds from EERE, are obligated to acknowledge the public interest when filing for patents. The information enables identification from

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[50] Patents have a central role in the innovation system, are generally considered closer to application than publications, and, as noted by Jaffe and Trajtenberg (2005), have been used extensively in the study of technological change. Tracing patent citations of scientific papers is a method of finding early influences of laboratory research on innovation.

[51] An overview of patent analysis is provided by Ruegg and Thomas (2013), and of bibliometrics by Hicks and Melkers (2013).

these larger databases of those patents that were assisted by DOE. The Web of Science contains extensive bibliometric records.[52]

That said, difficulties may arise in obtaining reliable databases for evaluation of EERE portfolios. In the case of patents, complexities that may be encountered include the following:

1) EERE funds relevant R&D across many organizations, and most patents resulting from EERE funding are not assigned to EERE.
2) Some assignees omit acknowledging the public interest. Even if the public interest is noted, a given patent may not be identifiable as resulting from the EERE portfolio of interest.
3) EERE may have funded part, but not all of the R&D underlying the patent, clouding the need for acknowledging public interest.
4) There may be a lag between database entry of patents or publications and the evaluation study, such that some may not yet be entered into a given database, including the OSTI database.
5) The portfolio may deal with a subset of a research area that causes it to be difficult to identify the subset of relevant patents from the titles that should be included in the evaluation data set.

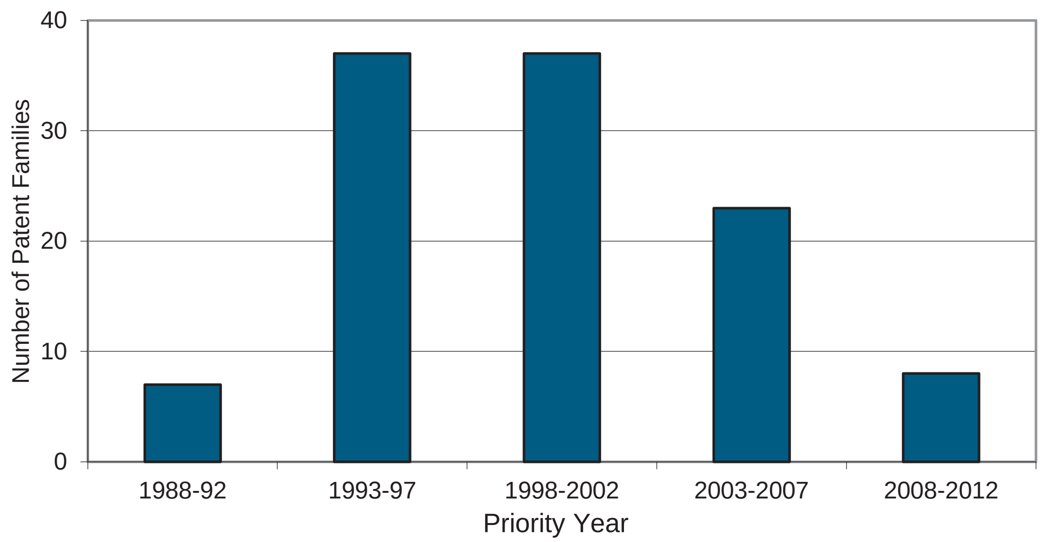
For all of these reasons, past evaluation studies have found it necessary to use a variety of approaches to construct the relevant EERE database needed for the evaluation.

Once the set of relevant patents have been identified, it is necessary to avoid double counting that can arise for two reasons: (1) organizations often file for protection of their inventions across multiple patent systems, such that the same patent exists with different designations; and (2) patent filers may apply for a series of patents all based on the same underlying invention. To avoid double counting, evaluators will need to construct "patent families" which group patents around their original patent. Thus, there are fewer patent families typically than there are patents.

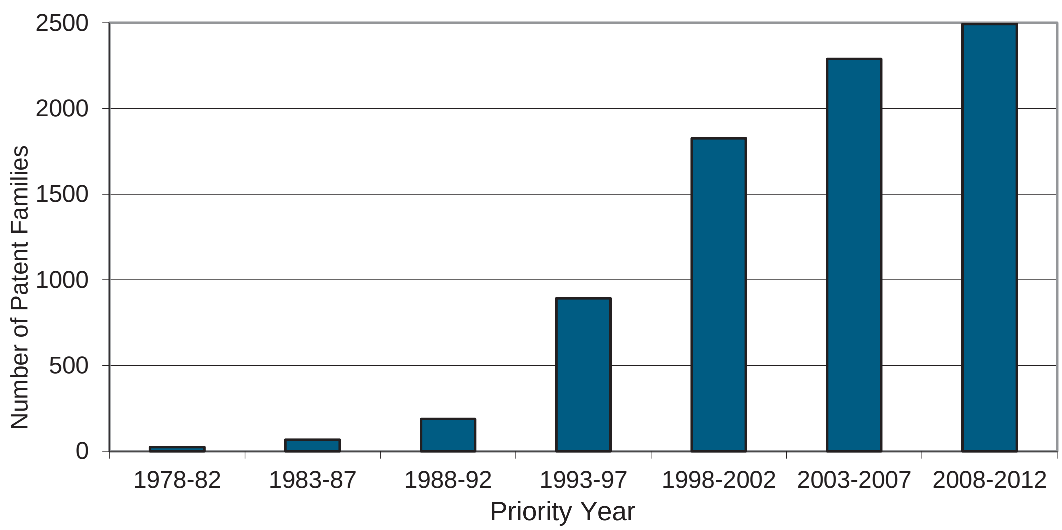
It is helpful to show the trend in output of relevant EERE-attributed patent families and publications, and, if feasible, to compare these with overall outputs. For example, Figure II.6-1 (parts a & b) shows the output of patent families attributed to EERE and overall. The illustration is from a recent evaluation of EERE's portfolio of energy storage technologies (including li-ion, NiMH, and ultracapacitors) for hybrid and electric cars.

In addition to compiling a database containing patents and publications attributed to the EERE portfolio, additional databases will be needed. To perform comparisons and to trace from commercial innovations back to earlier EERE R&D investments, evaluators will need to identify relevant organizations that are leading innovators/commercializers in the technology area of focus and construct a database of their patent portfolios in the area of interest. To provide country comparisons, the evaluator will need to construct relevant patent databases by country of first issue. To identify highly significant patents, evaluators will need to use citation indices to adjust for technology area and year of issue. Examples and discussion of how such additional databases are constructed are found in Ruegg and Thomas, 2013. In addition, previously conducted analyses of

[52] For EERE portfolios evaluated to date, a large share of publications have comprised technical reports and conference papers and presentations, and a smaller share, journal articles. The composition of publications affects the most suitable search engine to use.



Part a: Patent Families Attributed to EERE's Vehicle Technologies Office (VTO)



Part b: Overall Patent Families

Note: "priority year" refers to the date of filing of the original patent around which a family of related patents is based. Energy storage patents include li-ion, NiMH, and ultracapacitors.

Source: Table by Ruegg and Thomas, appearing in Link et al. (2014).

Figure II.6-1 Counts of Energy Storage Patent Families by Priority Year

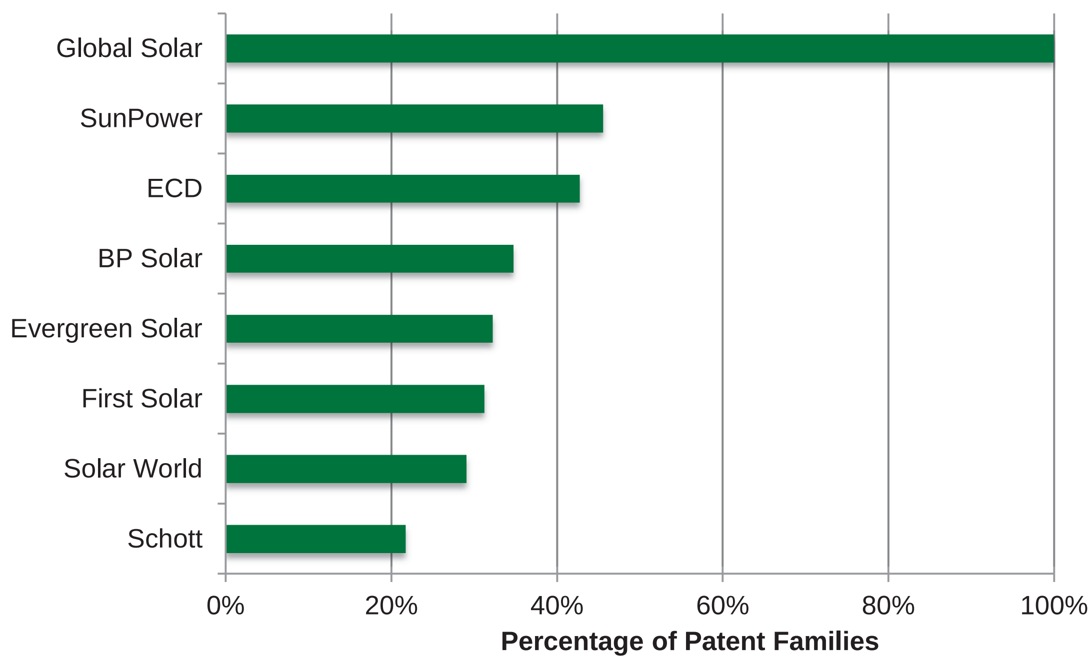
knowledge benefits in support of past evaluation studies show how various techniques were carried out, such as specifying filters for identifying patent sets.[53]

6.B Conduct patent citation analyses

Patent citation analysis can be used to compare knowledge influences of EERE with those of other organizations. Backward patent citation analysis in particular is useful for assessing how the patents of the leading company innovators in the targeted industry link back to the EERE-attributed set.

Backward tracing begins with a downstream technology/product/company and traces upstream to find earlier sources of influence. This approach is illustrated by Figure II.6-2, which is taken from a solar photovoltaic knowledge benefits study by Ruegg and Thomas (2011), performed in support of the solar photovoltaic benefit-cost study by O'Connor et al. (2010).

To determine linkages of the program portfolio not only to the targeted industry but beyond to other industries, forward citation analysis is used. This approach starts with EERE portfolio-attributed patents and identifies all subsequent patents that link back to these earlier EERE portfolio-attributed patents.



Source: Ruegg and Thomas, Solar Photovoltaic (2011)

Figure II.6-2 Percentage of Solar Energy Patent Families of Top U.S. Solar Photovoltaic Producers Linked to Earlier EERE-Attributed Solar Photovoltaic Patents

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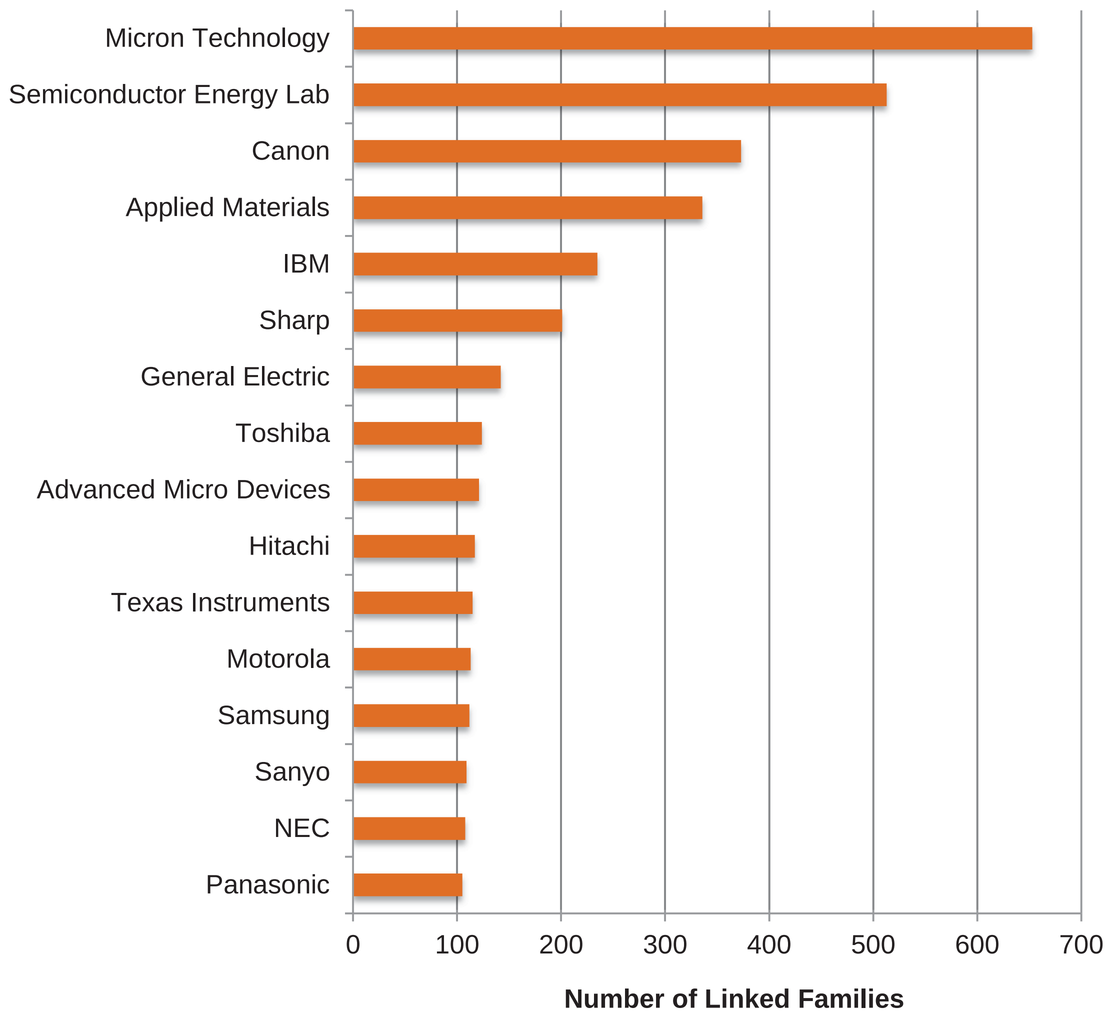
[53] See Ruegg and Thomas, 2011.

An illustration of forward tracing at the organizational-level is provided by Figure II.6-3, which is also taken from the solar photovoltaic knowledge benefits study by Ruegg and Thomas (2011). It shows the influence of EERE's investment in solar photovoltaic research to extend beyond the U.S. leading solar photovoltaic producers to leading companies in the semiconductor industry.

Patent-to-publication citation analysis can be used to identify when a subsequent technological invention has drawn directly on a scientific paper. Thus an extended feature of the patent citation analysis is to assess portfolio papers and publications that are cited by patents as prior art. An example is provided by Table II.6-1, drawn from a knowledge benefits study by Ruegg and Thomas (2011) for use in the related benefit-cost evaluation of EERE's Geothermal Technologies Office by Gallaher et al. (2010). The table lists papers and publications on thermal cement technology cited by thermal cement patents.



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

Figure II.6-3 Organizations from All Industry Areas with the Largest Number of Patent Families Linked to Earlier EERE-Attributed Solar Photovoltaic Patents

Table II.6-1 EERE Geothermal Portfolio Paper/Publications Linked to the largest Number of Patent Families through Two Generations of Citations

# Linked Patents	EERE Portfolio 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 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 et al., J*ournal 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 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).

6.C Identify notable knowledge outputs and innovations attributed to or linked to the EERE portfolio

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 is generally cited frequently by later patents.[54]

Examples of notable (i.e., highly cited) solar photovoltaic patents of leading companies that are linked back to EERE-attributed solar photovoltaic patents are given in Table II.6-2. The table is drawn from the Ruegg and Thomas knowledge benefit study performed in support of the 2010 solar photovoltaic benefit-cost study. 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 the 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.

6.D Apply additional techniques to assess knowledge benefits as budget permits

Other techniques may be used to extend the assessment of knowledge benefits from patent and publication analyses. Among these techniques are licensing analysis, publication co-authoring analysis, and network analysis. The potential use of additional methods of assessing knowledge benefits should be discussed with EERE staff while formulating the evaluation plan.

Interviews with EERE program staff may indicate an important role of intellectual property licensing as a knowledge transfer mechanism. In this case an analysis of licensing is needed. The analysis of EERE's investment in energy storage, for example, showed notable development of NiMH battery technology by ECD Ovonic, supported by EERE funding. ECD Ovonic subsequently licensed its NiMH patents to many prominent worldwide companies who developed NiMH batteries for hybrid and electric vehicles. Investigation of patent infringement cases may also shed light on knowledge creation and dissemination. Royalty payments linked to licensing can also provide an indication of the use and importance of the new knowledge.

As another example, the formation of collaborative R&D networks may be an important tacit means of knowledge dissemination. The evaluation study may find it worthwhile to construct diagrams showing collaborative relationships such as that shown in Figure II.6-4, taken from a study by Ruegg and Thomas (2010) in support of an evaluation study by Link (2010). It depicts networking arising from EERE's investment in the EERE/ACE R&D in advanced combustion engines. Alternatively, it may be feasible to apply social network analysis and develop networks and related metrics to assess how relationships change after the EERE investment is made.

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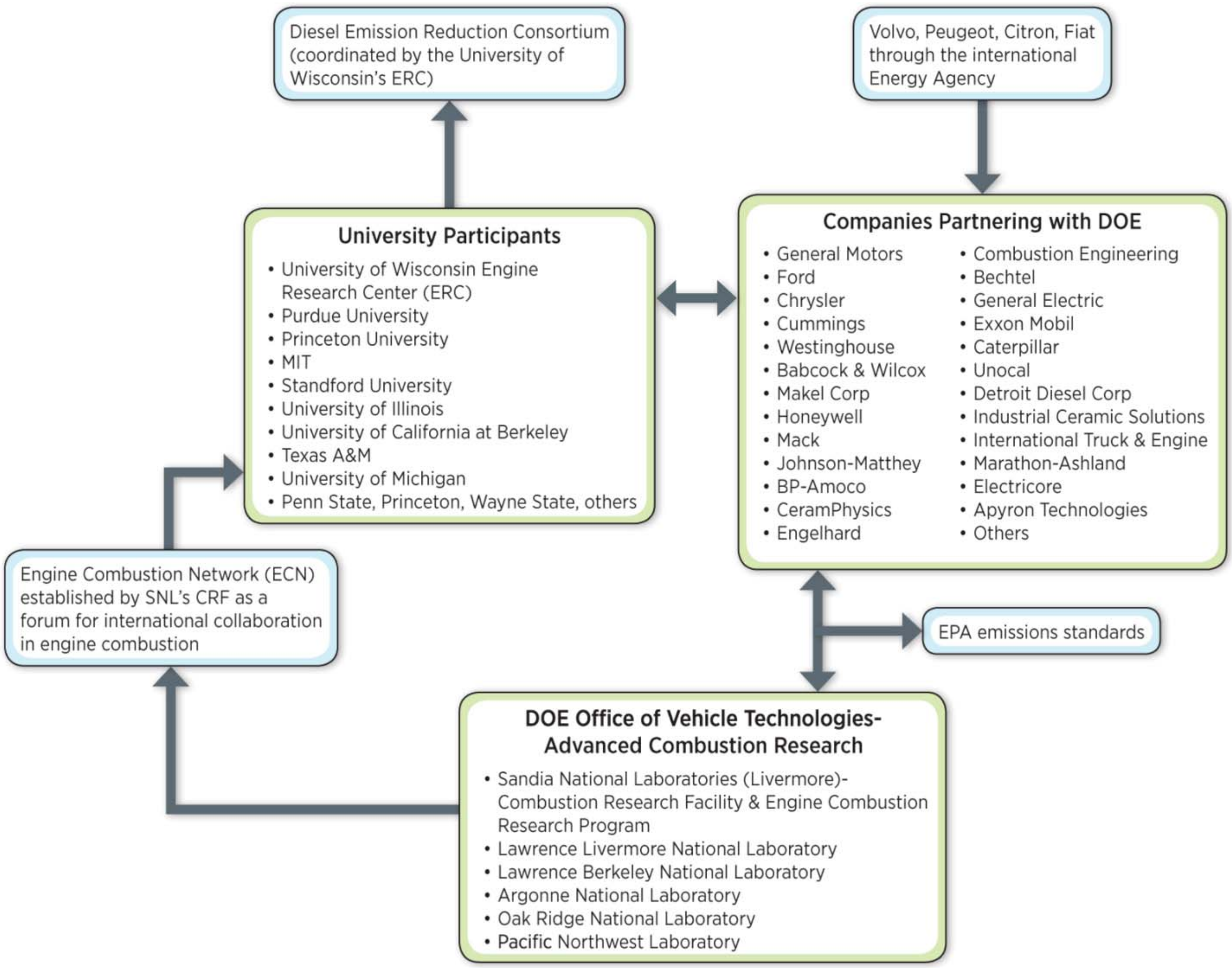
[54] This does not mean that every highly cited patent is important, or every infrequently cited patent is unimportant, but, research studies have shown a correlation between the rate of citations of a patent and its technological importance. See Bretzman and Mogee (2002).

Table II.6-2 Highly Cited Solar Energy Patents of Top U.S. Solar Photovoltaic Producers Linked to Earlier EERE-Attributed Solar Photovoltaic 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 photovoltaic (2011).



Source: Ruegg and Thomas (2010), as used in the related benefit-cost study by Link (2010)

Figure II.6-4 A Network of Organizations Facilitates Combustion Knowledge Creation and Flow

6.E Consider if and how knowledge-benefit findings inform the attribution analysis of Step 2

The results of the backward tracing citation analysis shows the extent to which patents of downstream company innovators and commercial product developers in the field are linked to patents attributed to the EERE portfolio, and, thereby, may support attribution. See, for example, Figure II.6-1 that links patents of top U.S. producers of solar photovoltaic modules to earlier EERE-attributed patents via citations. Details of highly cited EERE-attributed patents (not shown here, but provided in the report), and highly cited patents of others that connect back to EERE-attributed patents, as identified in Figure II.6-4, can help to show areas of specific EERE knowledge that were particularly influential. Similarly, licensing and royalty payments can show evidence of linkages of EERE's R&D to downstream innovators and developers.

While documentation of such linkages is supportive of there being cause and effect relationships between the EERE's portfolio investment and estimated impacts, it is not proof of causation. Also, while suggesting areas and strength of influence, citation linkages do not provide acceleration measures or indicate the share of benefits attributable. Additional analysis generally will be needed for estimation of attribution.

6.F Provide summary metrics for knowledge benefits

Prepare a table of summary metrics for knowledge benefits, using the format shown in Table II.6-3. The illustrative data in the table are drawn from the knowledge benefits study by Ruegg and Thomas (2010), performed in support of the benefit-cost study of vehicle combustion engine technology by Link (2010).

The knowledge benefit studies conducted in support of the evaluation studies conducted to date have all included patent analysis, but, depending on the budget provided, have variously included other approaches, such as publication analysis, licensing assessment, historical tracing, including expert interviews, and network descriptions. Therefore, not all measures are available for every study. The knowledge benefits assessment in support of the combustion benefit-cost study, for example, included only patent analysis and a simple network description.

The standard measures in Table II.6-3 comprise a section of the report's summary metrics. The optional measures are included in the knowledge benefits section of the report but not in the report's summary metrics.

Table II.6-3 Example Knowledge Outputs and Outcomes: Summary Metrics

Knowledge Outputs (partial, covers period mid-1970s-2008)	Units	Combustion Study Results
Standard Measures		
DOE-attributed patents	Number of patent families	109 patent families (i.e., groups of patents based on the same invention), containing 127 patents filed with the U.S. patents (USPTO), 14 with the European Patent Office (EPO), and 25 patent with the World Intellectual Property Organization (WIPO) (Represents less than 1% of the total number of combustion patent families of the 10 leading companies.)
EERE rank among organizations in terms of having its patents in the target industry cited by later patents of others in the field	Rank	Second ranked
Organization with rank higher than EERE	Organization(s) ranked higher	Nissan was first ranked
Spillover areas	Highest Rated IPC Grouping after targeted area	Detection and analysis of materials
Examples of high-impact EERE-attributed patents — subject areas	Patent Citation Index (CI) Value	Homogeneous Charge Compression Ignition (HCCI) (CI 8.51); Mixed mode fuel injector (CI 6.05); and Ion mobility spectrometer (CI 5.41)

Note: Completed using results from Ruegg and Thomas (2010) Patent Study for Vehicle Combustion Engine R&D.

II.7 Calculate Measures of Economic Performance

7. Calculate Measures of Economic Performance

- Compute economic performance measures for level-one analysis.
- Compute economic performance measures for level-two analysis.
- Compute economic performance measures for level-three analysis.
- Prepare a graph showing cumulative benefits by category, versus portfolio investment cost.
- Characterize how worthwhile the EERE portfolio investment has been, taking into account each level of impacts considered.
- Perform a threshold or break-even analysis if negative impacts have been revealed by any of the supporting qualitative analyses.

Economic performance measures are computed based on monetized benefits and costs in six sub-steps. They are calculated for three levels of analysis (see highlighted textbox.)

7.A Compute economic performance measures for level- one analysis

Economic performance measures are calculated by adding benefits by category successively in three levels of analysis and comparing benefits against portfolio investment costs.

The first level of analysis—Level 1—follows the traditional practice of comparing energy and other resource benefits valued in dollars against investment cost. The next two levels of analysis introduce environmental spillover impacts:

Level 2 incorporates an environmental spillover effect for health benefits from reduced air emissions. Level 3 incorporates an additional environmental spillover for intergenerational benefits from changes in GHG emissions. Portfolio investment costs remain unchanged for each level.

Three Levels of Analysis

- **Level 1**: computes economic returns by comparing energy and other resource benefits valued in dollars against portfolio investment cost.
- **Level 2**: adds to Level 1, a second stream of benefits—environmental health benefits valued in dollars—and compares combined benefits against portfolio investment cost.
- **Level 3**: adds to Level 2 benefits, a third stream of benefits—intergenerational environmental benefits associated with changes in GHG emissions valued in dollars — and compares combined benefits against portfolio investment cost.

As environmental spillovers are introduced into the analysis, it is assumed that uncertainty increases and the known precision decreases, particularly with the addition of intergenerational benefits from changes in GHG emissions. The three levels of analysis helps to reflect the increasing uncertainty and decrease in precision as the two types of environmental spillovers are added in turn. EPA's environmental health modeling tools have advanced rapidly and are widely used and accepted, and as such the environmental spillovers computed using COBRA are sufficiently robust to include in the Level 2 analysis that adds indirect environmental health impacts to direct resource impacts. For the calculation of intergenerational impacts from changes in carbon emissions, the results are considered more uncertain, and are thus presented in a Level 3 analysis.

To perform the Level 1 analysis, bring forward from Step 1 the total year-by-year cash flows for investment costs. Second, bring forward from Step 3 the total year-by-year cash flows estimated for energy and other resource impacts, ensuring that all amounts are expressed in constant dollars as of the last year of the study period.

Use the total summary year-by-year benefit and cost cash flows from Steps 1 and 3 to calculate each of the five economic performance metrics for level 1. Ensure that calculations conform to the descriptions in Table I-1, and the formulae in Table II.7-1. Ensure that the standardized conventions specified in Table II.7-2 are followed in adjusting current dollars to constant dollars, in discounting, and in calculating the economic performance metrics.[55] (Spreadsheet and other computer programs can be used, provided these requirements are met.)

(1) Sum year-by-year constant dollar undiscounted investment costs and year-by-year constant dollar undiscounted benefits based on energy and other resource impacts. The latter provides a measure of undiscounted Gross Benefits (GB).
(2) Calculate the present value (PV) of the year-by-year constant dollar investment costs (PV investment) for discount rates 7% and 3%. Calculate the PV of the year-by-year constant dollar benefits based on energy and other resource impacts (PV-benefits) by discounting the year-by-year amounts using first a 7% rate and then a 3% rate. These PVs will be used as the denominator and numerators, respectively, of the BCRs calculated in item (4) below.

Table II.7-3, draws from the 2013 EERE evaluation report by Link et al. (2013) to illustrate year-by-year and total investment costs, undiscounted and discounted, for the Vehicle Technologies Investment in Energy Storage Technologies for Hybrid and Electric Cars and Trucks. Table II.7-4 shows the year-by-year and total attributable energy savings from the same evaluation report.

(3) Subtract year-by-year undiscounted investment costs from year-by year undiscounted benefits based on energy and other resource impacts, and sum the results to provide a measure of total undiscounted Net Benefits (NB).
(4) Divide PV-economic benefits by PV-investment costs, first using the PVs based on 7% and then on 3%, to provide measures of Benefit-to-Cost Ratios (BCRs).

[55] Note that these requirements are intended to promote a more standardized approach, and to limit variation among studies that result only from following different conventions.

(5) Use the year-by-year undiscounted Net Benefits in constant dollars (not the total) to calculate the Internal Rate of Return (IRR).

Table II.7-1 Calculating Economic Performance Measures

Measure	Formulation
Total Investment Cost (I)	A simple summation of year-by-year constant dollar portfolio investment costs over the evaluation study period, i.e., $I = \sum_{y=1}^{N} Iy$, where Iy is an undiscounted constant dollar portfolio investment cost in year y and N is the number of years in the study period.
Gross Benefits (GB)	A simple summation of total benefits measured in dollars. This computation excludes both the EERE investment cost (I) and the required rate of return, as indicated by using an implied 0% discount rate; hence, it is only a partial measure of economic performance, i.e., GB = $\sum_{y=1}^{N} By$, where By is an undiscounted constant dollar benefit in year y (computed net of noninvestment costs in that year), and N is the number of years in the study period.
PV - investment	Present value of investment costs, i.e., PV-investment = $\sum_{y=0}^{N-1} Iy/(1+d)^{y}$, where Iy is an undiscounted constant dollar portfolio investment cost in year y , N is the number of years in the study period, *d is the discount rate,* and investment costs are assumed to occur at the beginning of each year.
PV- benefits	Present value of benefits, i.e., PV-benefits = $\sum_{y=1}^{N} By/(1+d)^{y}$, where By is an undiscounted constant dollar benefit in year y (computed net of noninvestment costs in that year), N is the number of years in the study period, *d is the discount rate,* and benefits are assumed to occur at the end of each year.
Net Present Value (NPV)	Net present value of benefits less Investment costs, i.e., NPV = $\{\sum_{y=1}^{N} By/(1+d)^{y}\}$ - $\{\sum_{y=0}^{N-1} Iy/(1+d)^{y}\}$, where all terms are as previously defined.
Benefit-to-Cost Ratio (BCR)	Ratio of PV-benefits to PV-investment, i.e., BCR= $\{\sum_{y=1}^{N} By/(1+d)^{y}\}$ / $\{\sum_{y=0}^{N-1} Iy/(1+d)^{y}\}$, where all terms are as previously defined.
Internal Rate of Return (IRR)	The real interest rate solution value (i) for which PV-benefits = PV-investment, NPV = 0 and BCR = 1, when inserted in the following equality: $\{\sum_{y=1}^{N} By/(1+i)^{y}\}$ - $\{\sum_{y=0}^{N-1} Iy/(1+i)^{y}\}$ = 0, where all terms are previously defined.

Table II.7-2 Summary of Standardized Conventions for Computing Constant Dollar Cash Flows, Discounting, and Computing Economic Performance Measures

Standardized Conventions	Instructions
Discount Rates	Use 7% and 3% real discount rates for discounting all constant dollar cash flows per OMB Circulars A-94 and A-4, respectively. The 7% discount rate is the primary rate for this evaluation, with the 3% rate presented for informational purposes. For intergenerational discounting with the SCC in Level 3, a 3% discount rate should be used in combination with both the 7% and 3% intragenerational Level 2 values.
Constant Dollars	Convert all cash flows to constant dollars as of the last year of the evaluation study period, and do this prior to discounting; i.e., if the study is conducted primarily in 2013, all current dollar cash flows would be adjusted to constant 2012 dollars prior to computing economic performance measures. Make the conversion using annual Gross Domestic Product (GDP) Implicit Price Deflators from U.S. Department of Commerce's Bureau of Economic Analysis (BEA), available at http://www.bea.gov/national/index.htm. The price deflators are routinely updated by BEA. Check with EERE program staff to determine if it is specifying a given BEA series to use; if not, use the most recently available annual series from BEA at the time of the study.
Study Period	Define the study period as beginning upon the onset of investment costs, and ending on the last day of the year near the time the study is conducted and for which data are available; i.e., if the study is conducted primarily in 2013, and if investment cost for the portfolio began in 1986, and data are available through 2012, the study period would be set as the beginning of 1986 through the end of 2012.
Cash-Flow Modeling	Model investment costs as though they occur at the beginning of the year in which they occur, and model benefits as though they occur at the end of the year in which they occur. [56]
Time for Expressing Present Value Amounts (Base Year)	Express all present value amounts as of the beginning of the year in which the onset of cash flow begins; i.e., if first cash flows occur in 1986, the study period begins in 1986, and all amounts will be discounted back to the beginning of that year, i.e., in this illustration, all present values will be stated as a lump-sum equivalent amount occurring as of the beginning of 1986.[57]
Use of Five Different Performance Measures	Compute and report each of the five measures defined in Table II-7-1.

[56] It is recognized that cash-flow modeling conventions vary and include beginning of year, end of year, beginning of year for investment cost and end of year for other cash flows, middle of year, and continuous through-out the year models. These are merely conventions rather than true representations of actual cash flows. Cash-flow modeling conventions are considered appropriate for evaluations; more exact cash flow representation is used for financial transactions. To promote consistency, evaluators must follow the cash flow modeling convention specified in the table.

[57] Because evaluation studies subject to the Guide will be conducted at different times and will address different portfolios, it is considered infeasible to require consistency of study period, year in which constant dollars are stated, and base year for stating present values. Instead, these variations can be adjusted to a common basis across studies at a later time if needed by EERE.

Table II.7-3 Illustration of Year-by-Year and Total Investment Costs for the Vehicle Technologies Office R&D Investments in Energy Storage Technology, 1992-2012

Year	(1) VTO R&D Investments (thousands of 2012$, rounded)	(2) VTO R&D Investments Discounted at 7% to 1/1/1992 (thousands of 2012$)	(3) VTO R&D Investments Discounted at 3% to 1/1/1992 (thousands of 2012$)
1992	39,783	39,783	39,783
1993	45,557	42,577	44,230
1994	51,699	45,156	48,731
1995	39,200	31,999	35,874
1996	37,145	28,338	33,003
1997	34,763	24,786	29,987
1998	37,397	24,919	31,319
1999	30,272	18,852	24,614
2000	30,474	17,736	24,056
2001	35,234	19,165	27,004
2002	33,375	16,966	24,834
2003	30,051	14,277	21,709
2004	26,987	11,983	18,928
2005	29,832	12,379	20,314
2006	31,444	12,195	20,788
2007	48,238	17,484	30,962
2008	52,128	17,658	32,484
2009	77,347	24,486	46,796
2010	82,035	24,271	48,187
2011	84,778	23,442	48,348
2012	93,034	24,042	51,511
Totals	970,773*	492,491**	703,463***

*Total undiscounted Investment Costs; **Total PV-investment @7%; ***Total PV-investment @ 3%.
Source: Link et al. (2014).

Table II.7-4 Illustration of Year-by-Year and Total Attributable Energy Savings, Vehicle Technologies Office R&D Investments in Energy Storage Technology, 1992-2012

Year	(1) Attributable Fuel Savings (thousands of 2012$)	(2) Attributable Fuel Savings Discounted at 7% to 1/1/1992 (thousands of 2012$)	(3) Attributable Fuel Savings Discounted at 3% to 1/1/1992 (thousands of 2012$)
1999	2	1	2
2000	1,611	876	1,235
2001	5,027	2,555	3,741
2002	10,773	5,118	7,783
2003	21,419	9,510	15,023
2004	43,500	18,051	29,621
2005	106,175	41,176	70,194
2006	187,326	67,896	120,237
2007	295,234	100,006	183,980
2008	423,230	133,984	256,061
2009	356,448	105,460	209,376
2010	461,639	127,647	263,266
2011	627,142	162,065	347,233
2012	736,723	177,928	396,025
Undiscounted total	3,276,249*		
Discounted totals		952,275**	1,903,777***

*Gross Benefits (GB); **Present value-benefits at 7%; ***Present value-benefits at 3%.
Source: Link et al. (2014).

Recall, as explained in Step 2, that the impact evaluation study may examine technologies that are characterized as infratechnology, technology platform, or product/process technologies. When the technologies selected from a portfolio for detailed analysis differ in their characterization and how they generate benefits, they are generally analyzed individually instead of as a group.

When technologies in a portfolio are analyzed individually, and their benefits are calculated separately, it may be desirable also to calculate their economic performance measures individually—in addition to the overall performance measures for the portfolio—provided that the individual investment costs can be obtained. The evaluator should work with EERE program staff in this case to determine (1) if the individual investment costs can be broken out of portfolio investment cost, and (2) if there is interest of EERE program staff in knowing the economic performance of the individual technologies that together make up return on the total portfolio.

An example of the separate reporting of economic performance measures for individual technologies within the portfolio is provided by the evaluation of geothermal technologies in the report by Gallaher et al. (2010). Table II.7-5, drawn from that report, shows individual returns for each of the four technologies selected for detailed analysis: PDC drill bit technology, binary-cycle plant technology, TOUGH reservoir computer models, and high-temperature cement—each quite distinctive, affecting energy and other resources in unique ways, and requiring different data sets and calculations to estimate benefits. (Not shown in Table II.7-5, but provided by the report, are the economic performance measures for the geothermal portfolio overall.)

Table II.7-5 Illustration of Separate Reporting of Economic Performance Measures for Individual Technologies Selected for Detailed Analysis (These are in addition to those provided for the Total Geothermal Portfolio)

	PDC			Binary			TOUGH			Cement		
Year	Total Benefits	Program Expenses	Net Benefits	Total Benefits	Program Expenses	Net Benefits	Total Benefits	Program Expenses	Net Benefits	Total Benefits	Program Expenses	Net Benefits
1976	$0	$2,081	-$2,081	$0	$2,036	-$2,036	$0	$797	-$797	$0	$142	-$142
1977	$0	$2,081	-$2,081	$0	$2,036	-$2,036	$0	$797	-$797	$0	$142	-$142
1978	$0	$2,081	-$2,081	$0	$2,036	-$2,036	$0	$797	-$797	$0	$142	-$142
1979	$0	$2,081	-$2,081	$0	$2,036	-$2,036	$0	$797	-$797	$0	$142	-$142
1980	$0	$2,081	-$2,081	$0	$2,036	-$2,036	-$3,158	$797	-$3,955	$0	$142	-$142
1981	$0	$2,081	-$2,081	$0	$2,036	-$2,036	$7,041	$797	$6,244	$0	$142	-$142
1982	$319,823	$2,081	$317,742	$0	$2,036	-$2,036	$3,495	$797	$2,698	$0	$142	-$142
1983	$400,600	$2,081	$398,519	$0	$2,036	-$2,036	-$6,065	$797	-$6,862	$0	$142	-$142
1984	$630,196	$2,081	$628,115	$2,114	$2,036	$78	$10,446	$797	$9,649	$0	$142	-$142
1985	$662,306	$2,081	$660,225	$2,047	$2,036	$11	$6,455	$797	$5,658	$0	$142	-$142
1986	$436,938	$2,081	$434,857	$9,822	$2,036	$7,786	$21,896	$797	$21,099	$0	$142	-$142
1987	$443,817	$1,844	$441,973	$14,398	$1,639	$12,759	$21,946	$797	$21,149	$0	$142	-$142
1988	$474,236	$1,683	$472,553	$3,750	$1,335	$2,415	$15,404	$797	$14,607	$0	$142	-$142
1989	$465,778	$1,601	$464,177	$8,238	$1,015	$7,223	$28,656	$797	$27,859	$0	$142	-$142
1990	$619,142	$1,490	$617,652	$15,229	$1,025	$14,204	$38,331	$797	$37,534	$0	$142	-$142
1991	$610,952	$1,586	$609,366	$7,337	$2,277	$5,060	$44,331	$797	$43,534	$0	$142	-$142
1992	$548,896	$1,575	$547,321	$15,926	$3,542	$12,384	$42,944	$159	$42,785	$0	$142	-$142
1993	$655,894	$1,455	$654,439	$26,175	$3,745	$22,430	$44,169	$159	$44,010	$0	$142	-$142
1994	$640,427	$1,335	$639,092	$6,700	$3,770	$2,930	$42,213	$159	$42,054	$0	$142	-$142
1995	$618,012	$1,341	$616,671	-$12,363	$2,890	-$15,253	$34,046	$159	$33,887	$0	$142	-$142
1996	$731,344	$1,474	$729,870	-$5,514	$1,844	-$7,358	$35,623	$159	$35,464	$0	$142	-$142
1997	$922,792	$1,558	$921,234	$3,362	$1,925	$1,437	$38,239	$159	$38,080	$0	$142	-$142
1998	$778,133	$1,817	$776,316	$978	$1,787	-$809	$37,958	$159	$37,799	$0	$142	-$142
1999	$564,958	$1,979	$562,979	-$391	$1,616	-$2,007	$37,664	$159	$37,505	$41	$142	-$101
2000	$862,685	$2,045	$860,640	-$2,399	$1,452	-$3,851	$33,581	$159	$33,422	-$123	$142	-$265
2001	$1,454,710	$2,188	$1,452,522	-$2,202	$1,203	-$3,405	$35,559	$159	$35,400	$1	$150	-$149
2002	$1,454,567	$2,188	$1,452,379	$2,226	$1,040	$1,186	$37,844	$159	$37,685	$165	$150	$15
2003	$2,025,308	$2,188	$2,023,120	$2,489	$971	$1,518	$37,994	$159	$37,835	$291	$150	$141
2004	$2,497,349	$2,188	$2,495,161	$1,721	$953	$768	$39,428	$159	$39,269	$472	$120	$352
2005	$3,429,701	$2,188	$3,427,513	$6,471	$972	$5,499	$38,802	$159	$38,643	$1,540	$130	$1,410

(Continued)

	PDC			Binary			TOUGH			Cement		
Year	**Total Benefits**	**Program Expenses**	**Net Benefits**	**Total Benefits**	**Program Expenses**	**Net Benefits**	**Total Benefits**	**Program Expenses**	**Net Benefits**	**Total Benefits**	**Program Expenses**	**Net Benefits**
2006	$4,631,182	$2,188	$4,628,994	$4,882	$972	$3,910	$38,797	$159	$38,638	$1,666	$150	$1,516
2007	$5,589,616	$2,188	$5,587,428	$2,677	$972	$1,705	$40,735	$159	$40,576	$1,811	$142	$1,669
2008	$6,081,340	$2,188	$6,079,152	$10,533	$972	$9,561	$41,817	$159	$41,658	$1,955	$142	$1,813
Undiscounted Total	$38,550,702	$63,178	$38,487,524	$124,206	$60,313	$63,893	$846,193	$15,455	$830,738	$7,820	$4,684	$3,136
PV[a] at 7%	**$7,813,212**	**$26,461**	**$7,786,751**	**$42,848**	**$26,819**	**$16,029**	**$219,445**	**$8,619**	**$210,826**	**$1,013**	**$1,938**	**-$925**
PV[a] at 3%	**$18,514,201**	**$41,015**	**$18,473,186**	**$76,269**	**$40,701**	**$35,568**	**$457,957**	**$11,655**	**$446,302**	**$3,199**	**$3,037**	**$162**
BCR at 7%	**295.3**			**1.6**			**25.5**			**0.5**		
BCR at 3%	**451.4**			**1.9**			**39.3**			**1.1**		
IRR	**139%**			**16%**			**48%**			**NA**		

[a] PV Base year is 1976.
Source: Gallaher et al. (2010).

7.B Calculate economic performance measures for level two of a three-level analysis

The level 2 analysis is accomplished by adding the environmental health benefits to Level 1 benefits and comparing combined benefits against total portfolio investment cost.[58]

Bring forward from Step 4 the year-by-year constant dollar cash flows for environmental health benefits, using the midpoint between the low and high estimates for each year, for each discount rate. Combine these benefits with energy and other resource benefits. Pair the combined year-by-year cash flows with the portfolio investment costs to calculate the five economic performance metrics described in Table II.7.1, while following the conventions specified in Table II.7-2 Table II.7-6 is an example drawn from the impact evaluation of engine combustion technology by Link (2010).

Table II.7-7 uses the combined benefits data from the last column of Table II.7-6 and the total portfolio investment costs to compute additional NPV, BCR, and IRR measures.

The table is drawn from the same impact evaluation of engine combustion technology by Link (2010).

7.C Calculate economic performance measures for level three of a three-level analysis

Bring forward from Step 4 the year-by-year constant dollar cash flows for GHG reduction and combine them with the other benefits data from Level 2. Compare the combined year-by-year cash flow impacts with the total portfolio investment costs to calculate the five economic performance metrics defined in Table II.7.1, following the conventions specified in Table II.7-2.

[58] As noted in Step 4, when calculating economic performance measures, the corresponding COBRA results should be used when estimating net present values and benefit-to-cost ratios. Use the 7% COBRA results when calculating performance measures with the 7% discount rate, and use the 3% COBRA results when calculating performance measures with the 3% discount rate. This is necessary because COBRA generates values using internal user-specified discount rates. Evaluators should be aware of how COBRA may affect the generation of the IRR for Level 2 economic performance measures and higher. When estimating the internal rate of return, evaluators should use the time series of values discounted at 7% with the understanding that there may be some slight bias to the overall internal rate of return. COBRA results are exogenous: when calculating the IRR results are not being iterated as the solution rate is sought. Since the values remain generated at a 7% discount rate, the internal rate of return on the stream of total net benefits will be slightly biased.

Table II.7-6 Combining Year-by-Year Energy and Other Resource Benefits* and Health Benefits

Year	Dollar Value of Economic Benefits* (Reduced Fuel Consumption) (millions $2008)	Economic Value of Avoided Adverse Health Incidence (millions $2008)	Combined 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
Level II Gross Benefits	$34,496.4	$35,704.8	$70,201.1

Source: Link (2010).
Note: the Link study did not use the "Level I and II" terminology. The economic value of avoided adverse health incidence was generated using a 7% social discount rate.
*At the time of the referenced study, energy and other resource impacts were called "economic benefits".

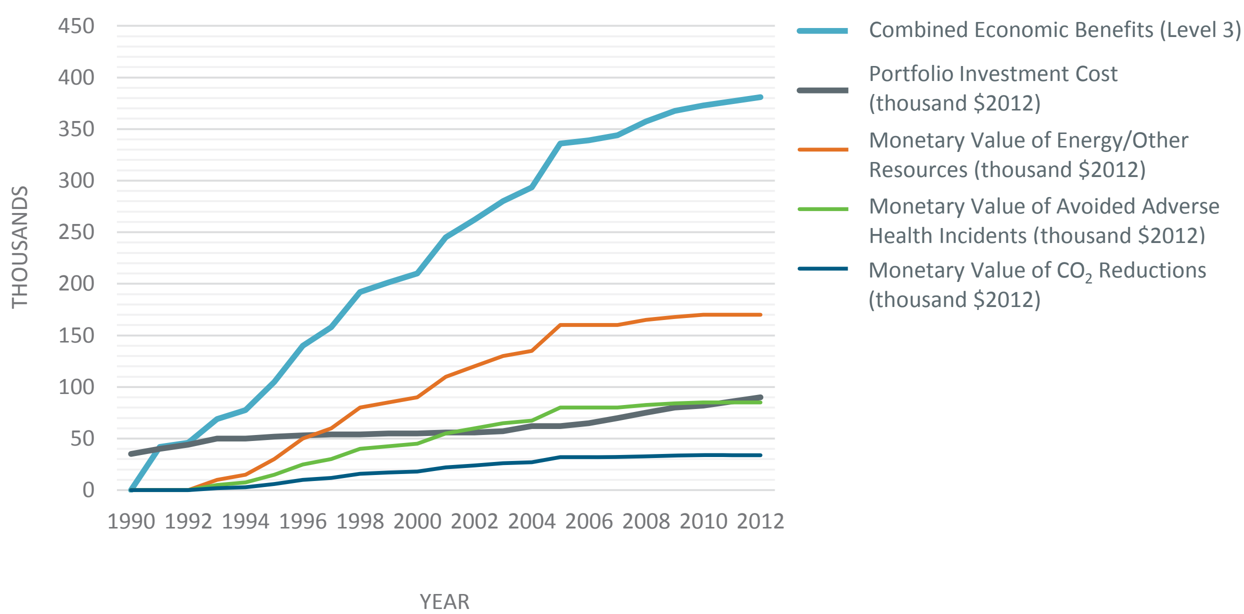
Table II.7-7 Example of Economic Performance Metrics Calculated from the Combined Energy and Other Resource Benefits* and Health Benefits Compared with Portfolio Investment Costs

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).
* At the time of the referenced study, energy and other resource impacts were called "economic benefits."

7.D Prepare a graph showing year-by-year benefits by category and for the total, together with portfolio investment cost

This is a new requirement in the Guide. Figure II.7 illustrates such a graph using hypothetical data to show all the elements that go into a Level Three analysis: monetary value of energy and other resource benefits, monetary value of avoided adverse health incidents , monetary value of GHG reductions, the combined economic benefits, and portfolio investment cost. Each of these cash-flow series is expected to be available for most evaluation studies, although it is possible that air emissions will not be affected by some technologies resulting in the need for only a Level 1 analysis.



Based on hypothetical data for purposes of illustration only.

Figure II.7 Illustration of Elements that Make up a Level Three Analysis

7.E Characterize how worthwhile the EERE portfolio investment has been based on monetized benefits and investment costs for each level of analysis considered

Discuss what the economic performance measures mean in terms of how worthwhile the EERE investment has been economically. The test that an investment has been economically worthwhile is that the NPV is positive, or that the BCR is greater than one, or 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 magnitude of these measures—the larger the measure, the more economically worthwhile the investment has been, others factors being equal. However, it is important to keep in mind that estimates for these economic performance metrics are conservative; they are based on partial benefits because not all benefits have been expressed in monetary terms. Benefits not expressed in dollars also contribute to how worthwhile an EERE portfolio investment has been.

7.F Perform a threshold or break-even analysis if sizable negative impacts have been revealed by any of the supporting qualitative analyses

The Guide recognizes that it may not be possible to measure all relevant impacts quantitatively—either in monetary or physical units. In cases where quantitative measurement either could not be done or was not required, the evaluator is instructed to provide qualitative treatments. As a result, there may be qualitative results for economic, environmental, and energy security impacts for the technologies selected for detailed analysis, as well as qualitative results for the part of the portfolio not selected for detailed analysis. It is expected that in most cases these qualified results will be either positive on net, adding to the returns from EERE's investment, and providing additional evidence that the economic performance measures represent conservative, lower-bound estimates or, at worse, neutral.

It is also possible, however, that there could be negative impacts that have been captured qualitatively. In this case, the evaluator should conduct a threshold or breakeven analysis, per the recommendation of OMB Circular A-4, to address the question, "How large could the combined value of negative nonquantified effects be before it would offset the NPV?" [59] In fact, this threshold or

How Worthwhile?

The economic performance measures indicate if, and to what extent, an investment has been economically worthwhile based on benefits express in dollars.

Conditions that must be met to show that a federal investment has realized or exceeded the required minimum acceptable rate of return on investment are the following:

$NPV \geq 0$, when $d=7\%$
$BCR \geq 1$, when $d=7\%$
$IRR \geq 7\%$

[59] Recall that the investment costs of "failed projects" are already taken into account. To offset NPV would require that there be projects in the portfolio that not only did not contribute on net to portfolio benefits, but actually reduced them.

breakeven value will be equal to the NPV of the impacts measured in dollars. Although the breakeven value appears self-evident, the breakeven analysis is recommended because it serves to focus attention on all impacts and explicitly considers the significance of impacts not included in the economic performance measures.

II.8 Account for Remaining Effective Useful Life (EUL) of Purchased & Installed Systems in an Extended Analysis

8. Account for Remaining EUL of Purchased and Installed Systems in an Extended Analysis

- Document EUL: of technologies selected for detailed analysis.
- Estimate remaining EULs.
- Estimate benefits for each year of remaining EUL.
- Calculate economic performance measures at level 3, inclusive of remaining EUL effects.
- Report results over the remaining EUL in a separate chapter.

The inclusion of benefits to reflect remaining effective useful life (EUL) of purchased and installed systems represents an extension of the retrospective analysis,in that they are future benefits not yet realized but are reasonably assured to accrue.

Effective useful life is the period over which an asset, such as plant, equipment, and systems and components, with normal maintenance and repair, can be expected to continue to be usable for the intended purpose.

An argument for the inclusion of these future benefits is that total portfolio investment costs include the R&D costs of systems that have only recently been purchased and whose benefits are expected to continue for years beyond the end of the retrospective analysis period. Further, the purchase decision has already been made, removing much uncertainty from the occurance of these future benefits. Thus, taking into account the remaining EUL benefits of those technologies selected for detailed analysis may represent a more balanced treatment of benefits and costs.

8.A Document EUL of technologies selected for detailed analysis

To take into account remaining EUL in an evaluation study, a starting point is to estimate the EUL of the major physical assets that represents the technologies selected for detailed analysis. [60]

[60] Because coverage of technologies by this Guide is quite broad (ranging from product technologies to infratechnologies, and from energy generating plants to vehicle batteries), the physical assets for which EUL may be needed are too varied to be named.

Information sources for EUL include the following:

- Product warranties;
- Supplier product documents;
- Records on past experience;
- Simulations of EUL;
- Interview of experts; and
- Literature review of related EUL studies.

If indications of the reliability of EUL estimates are available, this information should be collected for the purpose of performing sensitivity analysis. For example, records of past experience or reliability studies may express remaining life as a range or otherwise reveal data uncertainties.[61]

8.B Estimate remaining EUL

With EUL data in hand, it is possible to estimate the remaining EUL needed for the extended analysis for those units or systems installed or in operation by the close of the retrospective evaluation period.

By comparing the EUL with the time of purchase/installation and the cut-off time for the retrospective evaluation study, the remaining time over which the asset is expected to continue yielding benefits can be estimated. For example, for a system installed in 2010, with a 10-year EUL and a retrospective study period cut-off of 2012, the remaining EUL is eight years, i.e., two years have already been taken into account by the retrospective evaluation.

8.C Estimate benefits for each year of remaining EUL

For systems with remaining EUL, estimate the benefits for each year remaining beyond the retrospective study cut-off date. Take into account energy and other resources, environmental, and energy security benefits. Knowledge benefits need not be estimated because additions to the knowledge base relate to EERE's R&D investment and that does not change in relation to remaining EULs. For systems with extremely long remaining EULs, the evaluator may choose to impose a constraint on the time extension for assessing EUL effects.

To estimate the value of remaining EUL benefits, it is necessary to re-examine assumptions made for the retrospective evaluation and to determine if they apply to the future years over which benefits are to be estimated.

These considerations include if the next-best alternative identified in the Step 2 analysis will continue to apply and if other assumptions underlying the evaluation will continue to hold. If the next-best alternative is not expected to change and other estimating relationships are expected to hold, the same estimating algorithms that were used for the retrospective analysis can be used to extend the analysis.[62] If the next-best alternative is expected to change during the extended period, then it will be necessary to return to the beginning of Step 2 and repeat Step 3 (to calculate energy and other resource impacts over the extended period). Likewise, it will be necessary to repeat Steps 4 (environmental benefits) and

[61] For example, an EUL study sponsored by the California Public Utilities Commission (CPUC) of retrocommissioning (RCx) found high uncertainty for existing EUL data for situations under assessment, and concluded that a larger investigation was needed to provide reliable data. (Report of ACEEE Summer Study on Energy Efficiency in Buildings, 2010, John Roberts and Bing Tso, SBW Consulting, Inc., "Do Savings from Retrocommissioning Last? Results from an Effective Useful Life Study."

[62] Projected input data for future years, such as prices will be required.

5 (energy security effects) to calculate these impacts over the extended period. If underlying assumptions are expected to change, then the formulae for estimating impacts going forward should reflect that change.

If there are reasons to modify any of the underlying factors in the estimation, the evaluator should document the details of the modification(s) in the report chapter on EUL.

Show in tabular form the year-by-year series of remaining EUL benefits for each benefit category —i.e., for energy and other resources, environmental, and energy security benefits (but not for knowledge benefits). Also show totals in physical units for each benefit category over the period of remaining EUL. An example of the latter, i.e., total benefits in physical units for each benefits category, is provided in Table II.8-1. The table shows a side-by-side comparison of totals for the retrospective evaluation and for the extended analysis including remaining EUL, with all measures in physical units. The example is drawn from the evaluation of EERE's energy storage investment by Link et al. (2013). The retrospective evaluation stops at the end of year 2012. The extended analysis stops at the end of year 2022.

Table II.8-1 Illustration of Benefits for the Retrospective Evaluation (1992-2012) and the Extended Remaining EUL Analysis (1992-2022)

	Retrospective Analysis through 2012	Life-Cycle Analysis* through 2022	Unit of Measure
Energy and Energy Security Benefits			
Avoided petroleum consumption	54,199,182	111,870,462	Gallons of gasoline equivalent
Avoided foreign petroleum consumption	27,226,445	47,833,782	Barrels of oil
Emissions Benefits			
Avoided GHG emissions (CO_2eq)	6,989,237	14,461,042	Metric tons
Avoided volatile organic compounds emissions (VOCs)	3,928	7,926	Short tons
Avoided nitrogen oxides (NO_x)	1,217	2,324	Short tons
Avoided particulate matter emissions ($PM_{2.5}$)	2	16	Short tons
Avoided sulfur dioxide emissions (SO_2)	128	265	Short tons
Avoided ammonia emissions (NH_3)	643	1,329	Short tons
Environmental Health Benefits			
Incidence			
Avoided mortality[a]	20.04	42.39	Deaths
Avoided infant mortality[a]	0.02	0.05	Deaths
Avoided nonfatal heart attacks	6.96	14.73	Attacks
Avoided resp. hospital admissions.	4.34	9.17	Admissions
Avoided CDV hospital admissions	4.05	8.57	Admissions
Avoided acute bronchitis	18.24	38.57	Cases
Avoided upper respiratory symptoms	331.47	701.04	Episodes

(Continued)

Avoided lower respiratory symptoms	232.31	491.31	Episodes
Avoided asthma ER visits	7.79	16.48	Visits
Avoided MRAD	10,265.31	21,710.22	Incidences
Avoided work loss days	1,734.48	3,668.28	Days
Avoided asthma exacerbations	348.78	737.64	Episodes

Source: Link, et al. 2014.
*The labeling of this table column reflects the fact that the term "Life-Cycle Analysis" was used in the previous edition of the Guide to describe remaining EUL effects.

8.D Calculate economic performance measures for level 3, inclusive of remaining EUL effects

Using guidance provided in Step 7, calculate economic performance measures for a Level three analysis, taking into account remaining EUL effects. Hold portfolio investment cost unchanged because it already reflects the investment cost of the systems whose remaining EULs are taken into account.

Table II.8-2, also drawn from the evaluation study of EERE's energy storage investments, shows the side-by-side comparisons of economic performance measures for the retrospective analysis and the EUL-extended analysis. Because the study illustrated was performed prior to the requirement in this Guide for the monetary valuation of environmental benefits from reduction in GHGs, the illustration is based on combined energy and other resource benefits and environmental health benefits only. Evaluations performed under this 2014 edition of the Guide are to include extended combined total monetary benefits, including benefits from reduction in GHGs where applicable.

8.E Report the results over the remaining EUL in a separate chapter

In keeping with the principal focus on retrospective evaluation, report the extended EUL analysis and results in a separate chapter of the evaluation study report. Include documentation of: estimated EULs; uncertainties associated with these values; remaining EULs; the study period used in the extended analysis; and any changes in the next-best alternative or other underlying assumptions. Also include tables of benefit estimates year-by-year by category in physical and dollar units over the future period; investment cost used for the extended analysis (to confirm that investment cost has not been changed); and economic performance measures for the EUL-extended analysis in comparison with those of the original retrospective-only analysis.

If information is available on uncertainties of EULs, perform sensitivity analysis for the extended analysis results. Provide details of the analysis.

Describe the effects of including remaining EULs in the portfolio evaluation. Include in the report's Executive Summary a table that includes both retrospective and EUL results.

Table II.8-2 Illustration of Economic Performance Measures for a Retrospective Evaluation (1992-2012) and Remaining EUL Evaluation (1992-2022)

Measures based on combined energy and environmental health benefits	**Retrospective Analysis through 2012**	**Life-Cycle Analysis* through 2022**	**Unit of Measure**
Net present value @ 7% [Base year = 1992]	$506	$1,294	Million, 2012$
Net present value @ 3% [Base year = 1992]	$1,303	$3,334	Million, 2012$
Benefit-to-cost ratio @7%	***2.03***	***3.63***	
Uncertainty bound around BCR@7%	1.73—2.32	3.08—4.18	
Benefit-to-cost ratio @3%	2.85	5.74	
Internal rate of return	14.3%	17.7%	
Portfolio R&D Investments			
Present value @ 7% [Base year = 1992]	$492	$492	Million, 2012$
Present value @ 3% [Base year = 1992]	$703	$703	Million, 2012$
Economic (incl. Energy) Benefits			
Present value @ 7% [Base year = 1992]	$952	$1,706	Million, 2012$
Present value @ 3% [Base year = 1992]	$1,904	$3,836	Million, 2012$

Source: Link et al. 2014.
*The labeling of this table column reflects the fact that the term "Life-Cycle Analysis" was used in the previous edition of the Guide to describe remaining EUL effects.

II.9 Perform Sensitivity Analysis

9. Perform Sensitivity Analysis

- Identify areas of major uncertainty in the analysis.
- Recalculate results using alternative values for uncertain input variables, alternative assumptions, or alternative calculation approaches.
- Show sensitivity results in a separate chapter of the report.

Sensitivity analysis is a technique for determining how the evaluation outcome would change if uncertain inputs, assumptions, or modeling approaches were changed. It allows the evaluator to show uncertainty in the outcome by expressing results as a range of potential values rather than as a point estimate.

One case of sensitivity analysis built into the evaluation is the use of multiple alternative discount rates. The discount rate has a large effect on the economic performance measures NPV and BCR by incorporating a required real opportunity cost of capital into their calculations, and on IRR by setting a Minimum Acceptable Rate of Return against which the IRR must be compared.

The 7% real discount rate for EERE evaluations is the principal discount rate and is set by OMB for agencies to use for benefit-cost analysis aimed at determining if a given investment is worthwhile.[63] OMB recommends using other discount rates to show the sensitivity of the estimates to the discount rate assumption. Noting that the average real rate of return on long-term government debt has averaged about 3%, OMB directs the use of 3% real discount rate for benefit-cost analysis of regulatory programs.[64]

Although evaluations covered by this Guide are not for regulatory purpose, the Guide has adopted both discount rates. Seven percent is the primary rate and 3% is used for purposes of sensitivity analysis. In addition, by reporting undiscounted NB, the Guide in effect also uses a 0% discount rate. Thus, by basing results on discount rates ranging from 0% to 7%, the analysis shows the sensitivity of results to the discount rate.[65]

[63] OMB Circular A-94 (OMB 1992).

[64] OMB Circular A-4 (OMB 2003).

[65] Per OMB Circular A-94, the test to determine if an investment has been economically worthwhile requires that at least a 7% annual compound return on investment be realized.

9.A Identify areas of major uncertainty in the analyses

The following situations also warrant the use of sensitivity analysis:

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

9.B Recalculate results using alternative values for uncertain input variables, alternative assumptions, or alternative calculation approaches

Apply the following principles for the scenarios listed below. To test for sensitivity of results resulting from:

- A range of input values, use the low and high ends of the range to generate a range of outcomes. Table II.9-1, shows an example of the results of sensitivity analysis of environmental health benefits to two estimates of the displaced fuel mix by a geothermal plant.
- The distribution of responses from experts, use the upper and lower bounds of the distribution, or a statistical measure of variation. The example in Table II.9-2 shows sensitivity of solar photovoltaic results to a range of expert opinions on EERE's acceleration of technology advancement.
- Different estimation approaches, go to the stage of the analysis in which the estimation approach is used, substitute the alternative approach, and recalculate results. The example in Table II.9-3 shows sensitivity of results to using a different, but equally valid, approach to calculate the change in diesel fuel consumption from an improvement in truck brake thermal efficiency.

Table II.9-1 Sensitivity of Environmental Health Benefits to Displaced Fuel Mix of a Geothermal Power Plant

	Displaced Generation		Percentage Reduction
	60% Coal, 39% NG, 1% Oil	50% Coal, 50% NG	
PM (short tons)	22,193	18,780	15.4%
SO_2 (short tons)	9,614	7,992	16.9%
NO_X (short tons)	5,037	4,227	16.0%
GHG (thousand tCO_2e)	6,585	6,268	4.8%
Monetized health benefit (PV[a] at 7%, thousands $2008)	$126,644	$107,501	15.1%

[a] PV base year is 1976.

Source: Gallaher et al. (2010).

Note: The study obtained the applicable fuel mix for each state in which geothermal power was assumed likely to offset conventional power production and averaged the value of the mix across those states: 60% coal, 39% natural gas, and 1% oil. The primary analysis used this mix to calculate the change in air emissions and related environmental health benefits (col. 2). The sensitivity analysis used an alternative mix: 50% coal and 50% natural gas (col. 3). The percentage reductions in air emissions and related health benefits from using the alternative fuel mix are given in col. 4. Estimated health benefits would have been 15.1% lower if the alternative fuel mix had been used.

Table II.9-2 Sensitivity of Results to a Range of Expert Opinion on EERE's Acceleration of Flat-Plate Solar Array (FSA) Photovoltaic Technologies

Measure	Results (12-year acceleration)	Under 10-Year FSA Acceleration Effect	Under 15-Year FSA Acceleration Effect
Total benefits (million 2008$)	$18,734.8	$14,389.8	$25,875.7
Total costs (million 2008$)	$3,707.9	$3,707.9	$3,707.9
Net benefits (million 2008$)	$15,026.8	$10,681.8	$22,167.7
Internal rate of return	17%	14%	20%
NPV at 7% (million 2008$; base year = 1975)	$1,458.9	$858.8	$2,394.6
Benefit-to-cost ratio at 7%	1.83	1.49	2.37
NPV at 3% (million 2008$; base year = 1975)	$5,724.7	$3,987.2	$8,531.5
Benefit-to-cost ratio at 3%	3.24	2.56	4.35

Source: O'Connor et al. (2010)
Note: The study approach was to ascertain from experts when the photovoltaic technology advances would have been made in the absence of the EERE's solar photovoltaic investment. The range of opinion was 10-years to 15-years; the principal analysis used an average of 12-years. Sensitivity analysis shows the range of results when the low and high bounds of opinion are used.

Table II.9-3 Parts A and B. Sensitivity of Results to Using a Different Estimation Approach for Reduced Fuel Consumption

Part A. Results from Estimation Approach Used in Principal Analysis:

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).

Part B. Results from Using an Alternative Estimation Approach in the Sensitivity Analysis:

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 Link (2010).

In this latter example shown in Table II.9-3, two estimation approaches are used to estimate diesel fuel cost savings from an improvement in brake thermal efficiency (BTE)—a driver of benefits in the analysis of EERE's investment in advanced combustion engine efficiency. Note that the sensitivity testing does not show which of the two estimation approaches is better for estimating diesel fuel cost savings. According to the referenced evaluation report, either estimation approach could reasonably be used in the analysis. The sensitivity analysis, however, plays a helpful role by demonstrating that the outcome is quite strong regardless of which of the two calculation approaches is used.

9.C Show sensitivity results in a separate chapter of the report

In a separate chapter of the evaluation report, discuss uncertainties, identify areas selected for sensitivity analysis, and explain why and how these were selected. Show how the sensitivity analysis is performed. Explain how the results are affected by the use of alternative values or approaches, and discuss the implications. Present summary results of the sensitivity analysis in the evaluation report's executive summary.

II.10 Assess Technical and Market Context; Discuss Success Factors

10. Assess Technical and Market Context; Discuss Success Factors

- Characterize the portfolio's broader technological and market context.
- Assess EERE's program strategies.
- Provide actionable recommendations where possible.

In conducting economic impact analyses of EERE R&D portfolios, evaluators gain insight into the effectiveness of programs and investment initiatives and how they relate to technology development and market challenges. These insights are particularly valuable to EERE technical managers, program directors, and policy analysts because they illuminate possible success factors that could be replicated in other R&D initiatives. Similarly, they may help avoid repeating R&D investment shortcomings.

10.A Characterize the portfolio's broader technological and market context

Describe the beginning- and end-of-study technical conditions. Draw on the initial portfolio analysis from Steps 1-3—particularly the logic model analysis, the review of program records and other documents, and the interviews with experts to describe the technical conditions that characterized the beginning-of-study R&D environment for the subject technologies. Draw also on the results of the evaluation—particularly Steps 2-7—to describe the technical conditions that characterized the end-of-study R&D environment for the subject technologies. Address the following questions as applicable:

- What technical barriers were the subject EERE portfolio investment and the specific technologies drawn from the portfolio intended to overcome? What were the key technical objectives?
- To what extent were these technical objectives met?
- Were there other technical barriers standing in the way of achieving boarder technical goals even if those targeted by the evaluated portfolio investment were overcome?

Characterize the market environment faced by commercial products and processes incorporating the EERE-funded innovations. Address the following questions as applicable:

- Has the EERE investment improved an existing product or advanced development of a new product?
- What are the implications of the type of innovations for market entry?
- What is the state of the industry and market into which the resulting products or processes advanced by the EERE R&D investment are launched?
- What is the competitive situation faced by U.S. producers?
- Are there market barriers that may inhibit the diffusion of the technology into domestic and global markets even if the EERE investment is successful technically?
- Is there an EERE strategy that addresses market barriers?
- How large is the potential national and global market and who holds existing market share?
- What progress have commercialized products and processes incorporating the EERE-funded innovations made in penetrating new and existing markets?
- What is the market outlook?
- Are the major application areas those that were originally targeted by EERE? What are the most promising application areas, and how does past experience inform future EERE strategy and objectives?

An example of providing technological and market context for an EERE portfolio investment is provided by the evaluation of solar photovoltaic investment. The evaluation report explains how each initiative was a response to specific technical barriers and technology needs existing at the time the initiative was launched.

The solar photovoltaic evaluation study was able to obtain an industry study from the Massachusetts Institute of Technology's Energy Laboratory (Linden, L., et al, 1977) that identified primary market failures that

Study Context: Illustration of Providing an Account of Market Failures Existing at the Outset of EERE's Solar Photovoltaic Investment

- Energy prices that do not account for deleterious environmental or human health impacts associated with fossil fuel consumption and combustion.
- Production uncertainties concerning prices, availability, quality, reliability, production volumes, and the ready supply of renewable and fossil fuel technology alternatives.
- Technological uncertainties, particularly with respect to development costs, time, and R&D performance.
- Interdependencies of production and technology development, which are the confluence of uncertainties, indivisibilities, and externalities that impede market function through asymmetries in information and poor convergence of expectations.
- Indivisibilities, and inability to appropriate returns for technology development, such that, despite solar photovoltaics being in the national interest, the costs of developing and maturing the technology may preclude private-sector innovation if returns from innovation cannot be appropriated as profits within a suitable time horizon.
- Imperfections in financial markets attributable to the chasm between internal sources of funding and the risk-reward profile that influences private equity financing.

Non-competitive market structures that may inhibit new, competing sector development were inhibiting the development of terrestrial photovoltaics at the outset of the EERE photovoltaic investment. (See listing in the text box.)

The EERE solar photovoltaic evaluation report provides a historical timeline context for EERE's contributions by describing how each initiative built on earlier advances, and by reporting yearly progress. Table II.10-1, drawn from the EERE solar photovoltaic evaluation report, shows notable technology outcomes of the EERE photovoltaic initiatives against a timeline of U.S. solar photovoltaic industry progress from 1976 (the time of the initial EERE investment) to 2008 (the end of the study period). Progress is shown in terms of photovoltaic module production, production cost per watt, and years of reliability.

The solar photovoltaic evaluation report also provides accounts of the achievement of technical objectives by the EERE initiatives. For example, Table II.10-2 summarizes a sample of technical accomplishments under the Flat-plate Solar Array (FSA) development effort.

An illustration of providing market context is provided by the evaluation study of EERE investment in energy storage technologies for hybrid and electric cars and light trucks (Link et al., 2013). As the study points out in its evaluation of NiMH and Li-ion batteries, all electric and hybrid cars and trucks on the road today use either of these battery technologies. The study provides background market data to help provide context for understanding the significance of the technology and where it stands in terms of market penetration. Among the extensive background market data the study provides is that given in Figure II.10. The data are relevant because of the market interdependence of battery technology and electric-drive vehicles. Demand for the battery technology examined is dependent on sales of electric-drive vehicles. The availability of batteries with improved performance and lower cost in turn increases the performance and reduces the cost of electric-drive vehicles, and, thereby, increases demand for electric-drive vehicles and, in turn, demand for batteries.

This is only one example of the various market context measures that the evaluator can assemble to understand and explain the market context for an EERE research investment over its period of performance.

Table II.10-1 Illustration of Presenting Notable Technology Outcomes for each EERE Initiative against a Timeline of U.S. Photovoltaic Industry Achievements, 1976-2008

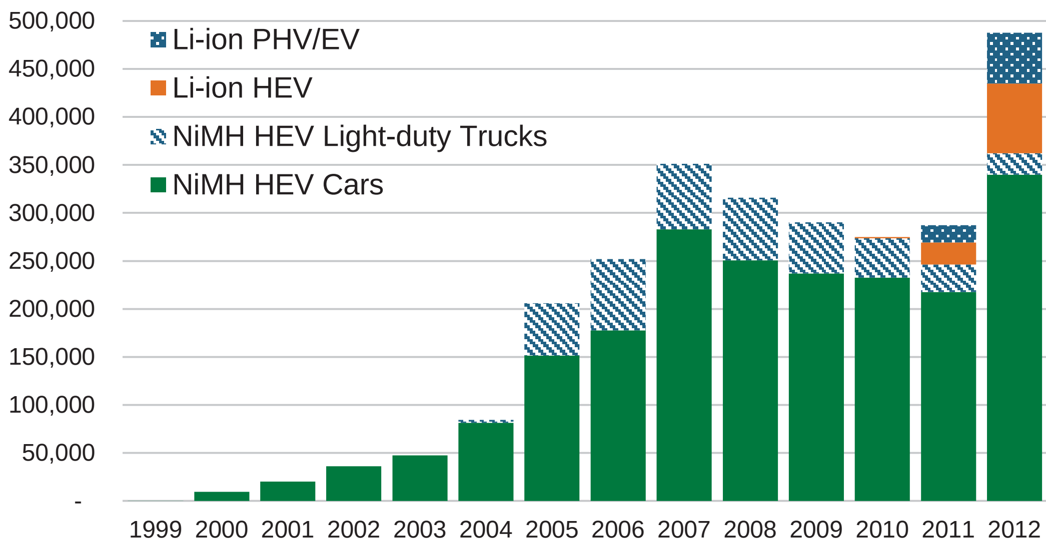
Year	Module Production (MW)			Production Cost ($/W)	Reliability (Years)	Notable Technology Outcomes
	c-Si	Thin Films	Total			
1974	0.19	0.00	0.19	$114.44	2	
1975	0.37	0.00	0.37	$83.86	2	
1976	0.80	0.00	0.80	$53.28	2	**Flat-Plate Solar Array Project** • Block Purchases I-V • EVA for encapsulants • UCC silicon refining process • Silicon ingot growth • Silicon ribbon growth • Automated module assembly • Design and test methods for durability, performance, and safety • Laboratory cells reaching 22% efficiency • 10-year module warranties
1977	1.22	0.00	1.22	$37.60	2	
1978	1.65	0.00	1.65	$25.64	2	
1979	2.07	0.00	2.07	$23.93	2	
1980	2.50	0.00	2.50	$22.22	2	
1981	4.46	0.00	4.46	$19.65	2	
1982	5.05	0.00	5.05	$17.09	5	
1983	5.63	0.00	5.63	$14.53	5	
1984	6.22	0.05	6.27	$11.96	5	
1985	7.30	0.50	7.80	$9.40	10	
1986	6.40	0.85	7.25	$8.99	10	
1987	7.45	1.40	8.85	$8.58	10	
1988	9.70	1.85	11.55	$8.16	10	
1989	12.95	1.45	14.40	$7.75	10	
1990	13.78	1.37	15.15	$7.34	20	
1991	16.48	1.00	17.48	$6.93	20	**Thin-Film PV Partnerships** • National teams • Basic research in a-Si, CdTe, and CIS • a-Si modules (ECD/Uni-Solar) • CdTe modules (First Solar [Solar Cells Inc.]) • CIS/CIGS modules (Global Solar) **PV Manufacturing Technology Project** • Wire saw technology adoption for silicon ingot wafering • Automated cell and module assembly processes • In-line diagnostics and monitoring • High-efficiency c-Si cells • Cost reductions from $6.93 per watt in 1991 to $1.92 per watt in 2008 • 25-year module warranties • Funded AstroPower (GE), BP Solar (Solarex), Evergreen, First Solar, Global Solar, SCHOTT Solar, SolarWorld USA (Arco/Siemens/ Shell), SunPower, Uni-Solar
1992	16.95	1.65	18.60	$6.00	20	
1993	20.91	1.53	22.44	$5.69	20	
1994	24.31	1.95	26.26	$4.84	20	
1995	33.30	1.66	34.96	$4.53	20	
1996	37.35	2.46	39.81	$3.93	20	
1997	48.00	3.10	51.10	$3.77	25	
1998	48.10	5.80	53.90	$3.71	25	
1999	53.80	7.00	60.80	$3.45	25	
2000	66.00	9.00	75.00	$2.96	25	
2001	86.70	13.80	100.50	$3.00	25	
2002	109.40	18.20	127.60	$2.85	25	
2003	86.82	15.80	102.62	$2.91	25	
2004	115.20	23.50	138.70	$2.80	25	
2005	133.60	44.50	178.10	$2.96	25	
2006	175.30	92.50	267.80	$2.67	25	
2007	189.20	263.00	452.20	$2.11	25	
2008	379.90	642.70	1,022.60	$1.92	25	

Source: O'Conner et al. 2010. Informational sources: O'Conner et al. 2010; Christensen (1985); *PV News* (Maycock, 1986–2004; *PV News*, 2005–2009); EIA and IEA (EIA, 2008; IEA, 2009); Friedman et al., 2005; Green (2005).

Table II.10-2 Illustration of Summary Accomplishments under FSA's Process Development Area (drawn from the evaluation of EERE's Solar Portfolio)

Surface Preparation	Metallization
Technological and economic feasibility studies of automated surface preparation Test patterns for process development and monitoring tools Industry-standard texturizing process Spin drying Silicon nitride as a multipurpose cell coating	Thick-film screenable cost-effective processes using Ag, AgAI, Cu, and MOD AgBi Reliable plating systems using Pd and Ni followed by solder build-up by immersion or Cu plating to provide conductivity MOD films for low-temperature contact systems Generic fabrication systems for MOD films
Junction Formation	**Module Fabrication**
Large-area, large-volume gaseous diffusion processes Spin-on, spray-on, and meniscus coating processes Simultaneous front and back junction-forming processes using liquid dopant and RTP NMA ion implementation of front and back junctions	Fully automated interconnect soldering equipment Fully automated ultrasonic bonding equipment

Source: Gallagher et al. (1986), as referenced by O'Connor et al. (2010).



Source: Link et al. (2013).

Figure II.10 Market Context Illustration: Number of Electric-Drive Vehicles Sold in the United States by Battery Technology, 1999-2012

10.B Assess EERE's program strategies[66]

Consider what strategies the program has used, and which of the program strategies assessed have been more, or less, successful in achieving stated goals. Identify and discuss any problems or remaining barriers that the study has uncovered. This is to be done in the spirit of sharing "lessons learned," with the objective of strengthening future EERE program strategies and their implementation. The evaluator should address the following questions:

- What strategies did the program pursue in achieving its portfolio objectives?
- Was there an observable difference in the effectiveness of strategies?
- What strategies appear to have worked well?
- What strategies appear to have worked less well?
- What barriers were encountered?
- Which barriers were overcome, and which were not?
- If possible, explain what accounted for different levels of success in achieving positive economic returns?
- What lessons can be learned from the R&D effort evaluated that can be translated into actionable recommendations for future similar EERE R&D investments?

This assessment may draw on interview data, it may present anecdotal evidence, and in other ways it may go beyond the presentation of formal analysis and numerical results. EERE program staff, industry participants and nonparticipants, experts in other organizations such as associations, and others may be asked their opinions about what worked well and what did not. They can be asked what they would have changed if they had it to do over again. Where there has been limited uptake of the technology by the market, potential adopters can be asked why they did not, and what they think it would have taken (or would take) to make the technology commercially successful. Were the remaining obstacles mainly technical problems? Were there prerequisite developments that did not happen as expected? Did competing technologies win out? Were there other barriers?

In short, the evaluator is expected to conduct investigative inquiries throughout the evaluation study to learn more about the technical and market research environment in which the EERE investment was made, the strategies pursued by EERE to achieve its goals, outcomes and impacts, and possible reasons why the subject technologies had or had not achieved economic success.

10.C Provide actionable recommendations where possible

There are a number of factors that could help explain why the technologies in the portfolio examined have or have not achieved technical and economic success. Based on the preceding assessment and resulting insights and lessons learned, the

[66] This formative analysis represents a new assignment in this edition of the Guide. In adding this task, EERE recognizes that in-depth formative evaluation is normally performed during the course of a program's implementation, and not as part of a long-term retrospective benefit-cost (or impact) study, such as that covered by this Guide. It is also recognized that conducting formative evaluation requires different experience and a different skill-set than conducting summative (or impact) evaluation requires. Moreover, impact evaluators may not necessarily be experts in R&D management or market analysis—expertise that may be needed to address some of the questions presented. The recommendation is for the evaluator to obtain market expertise as needed to conduct the evaluation as set forth by the Guide, and to share lessons learned during the course of conducting the evaluation study in a "best effort" mode.

evaluator is asked to list and discuss actionable recommendations. The objective is to provide feedback that can improve future similar program investments.

Where possible, provide recommendations, using the following questions listed by category for organizing recommendations.

- **R&D goals, scope, strategies, and program implementation plan:**
    - Were long-term goals of the R&D effort clearly defined and realistic?
    - Were goals in line with the broader research environment and national priorities?
    - Was the scope neither too narrow nor too broad?
    - Did the R&D effort include practical strategies designed to achieve targeted technical and market goals?
    - Was there adequate planning for program implementation?
    - To what extent was there successful execution of program strategies and activities?

- **Resources/inputs:**
    - Was funding sufficient to achieve goals?
    - Was the EERE funding provided in a timely way?
    - Were participants in the R&D effort successful in attracting third-party funding?
    - Was there sufficient time for achieving both technical and commercial goals?
    - Were challenges encountered in resource availability or timing?
    - Were any funding gaps identified and filled/ not filled?

- **Collaboration:**
    - Did it seem there was the right mix of research teams, private companies, private and government laboratories, universities, research associations, other parts of DOE, and customers involved in the R&D effort?
    - Was the research environment conducive to excellent work and goal achievement?
    - Were there any key elements missing?
    - If the collaboration was missing key elements, were remedies applied?

- **Alignment of technology and markets characteristics:**
    - Were technical challenges impeding progress adequately defined?
    - Were technical goals achieved?
    - Were technology achievements incremental or radical?
    - Was the marketing approach aligned with technology characteristics?
    - Were there prerequisite or supporting technology elements, and, if so, were they adequately addressed?
    - Was the technology sufficiently superior to its alternatives over an extended period to give it a clear market advantage?
    - Does the technology have potential for use in widespread and/or multiple applications?
    - Was a path to market envisioned that was suitable for characteristics of the technology and the innovators?
    - Was market demand present, accessible, and growing, or not?

- Did the R&D effort include deployment support? Was it effective?
- Was speed to market critical to success?
- Did the R&D effort accelerate technology development and commercialization?
- Has a domestic industry emerged?
- Has a robust domestic supply chain emerged?
- Is production moving offshore?
- What additional technical and market bottlenecks or barriers were encountered and were they successfully overcome?

- **Agility of the program and its partners to respond to change:**
  - Did the program modify its course of action in response to a specific need?
  - Did program partners modify their courses of action as needed?
  - Were there any external factors that threatened to derail program goals and strategies, and, if so, what was the program's response?

II.11 Report Results

11. Report Results

- Meet the stated standards of the report for content, format, presentation, transparency, and credibility.
- Present summary results in a uniform tabular format.
- Apply checklist.

11.A Meet the stated standards of the report for content, format, presentation, transparency, and credibility

The evaluator is expected to deliver a high-quality study report that meets the following standards:

- Effective tool for communicating with diverse program stakeholders to convey the study's method, findings, and implications;
- Highly consistent with other benefit-cost study reports performed according to the Guide and free of differences that are not necessitated by (1) changes in the Guide, (2) unique study requirements, and (3) data availability issues;
- Transparent in use of input data, assumptions, and calculations, allowing replication and verification of benefits and economic performance measures;
- Documents all data, assumptions, and calculations, and provides complete references to data and other sources. Presents summative evaluation contents including economic returns for up to three levels of analysis as needed; additional impacts including those reported using physical measures and qualitative descriptions; a separately reported extended analysis based on remaining system EUL; and sensitivity analyses to reflect uncertainties; and
- Presents formative evaluation contents consisting of evaluator's lessons learned and recommendations, derived from the evaluation and enhanced by conducting investigative inquiries to learn more about the environment in which the EERE investment was made, the strategies pursued by EERE to achieve its goals, and possible reasons why subject technologies in the portfolio had achieved economic success.

A feature of the body of the report and its executive summary is the inclusion of economic returns for up to three levels of analysis, as described in Step 7, and relisted below:

Level 1: economic returns computed by comparing the monetary value of energy and other resource benefits against portfolio investment cost.

Level 2: economic returns computed by comparing combined monetary value of energy and other resource impacts and environmental health benefits against portfolio investment cost.

Level 3: economic returns computed by comparing combined monetary value of energy and other resource impacts, environmental health benefits, and environmental benefits from reduction in GHGs against portfolio investment cost.

While three levels of analysis may not be needed for every evaluation study and report, evaluators should ensure that the appropriate level or levels have been provided. The number of levels needed depends on the benefits categories impacted by a given portfolio. Monetized benefits come from energy and other resource benefits, environmental health benefits, and environmental benefits from reduction in GHGs. The other two benefits categories—energy security benefits and knowledge benefits—are not valued in dollars, and, hence, do not affect the computation of economic returns. It is possible that a given technology will not generate environmental effects, such that only a Level 1 analysis will be needed.[67]

The report must be explicit in laying out the following contents concerning the evaluator's actual implementation of study method and data collection:

- Research questions
  - What are the specific researchable questions for the evaluation?
- Research design
  - What specific design is being used to answer the research questions and why is that the best design? Would it be sufficient for answering the questions of the evaluation?
- Study population
  - Who will participate in the study? How are they selected? What sampling approaches are to be used?
- Data collection
  - How would the data be collected (e.g., through survey, in-depth interviews, direct measurement and verification, focus groups, etc.)?
  - What instrument would be used for data collection?
  - Has the instrument been tested for validity and reliability? For example, is a measuring instrument capturing what it is supposed to capture? Or if a survey is being used, are the questions valid, properly phrased, properly sequenced, with appropriate skip patterns, etc.?
- Analysis
  - As described above, what levels of analyses are being done for the study? Provide a systematic presentation of the levels of analysis.
- Limitations
  - What are the design, validity threats, execution, and analysis issues that could not be overcome? Be transparent about the limitations of the study and provide appropriate caveats to the presentation of results.

11.B Present summary results in a uniform tabular format

Evaluators are asked to provide summary results in a uniform tabular format for easy accessing of impacts by readers. The tabular

[67] For example, the evaluation of a portfolio of geothermal technologies included PDC drill bits, for which the effect was measured in terms of non- energy costs. (Higher rates of penetration and reduced rental time for drill rigs.) Hence, for that technology evaluation, there were no environmental impacts, and a Level I analysis sufficed for that part of the portfolio evaluation. However, the overall geothermal R&D portfolio contained other technologies that did generate environmental impacts.

format presents summary results for overall economic performance, as well as a number of impacts stated in physical units rather than valued in dollars, and some described in words. The table, as shown presents the economic performance measures for up to three levels of analysis. It delineates between the purely retrospective benefits and the extension of benefits to include remaining EULs of retrospectively purchased/installed systems. A uniform tabular format is shown in Table II.11-1. At the discretion of the evaluator, the material in Table II.11-1 may be presented as a series of smaller tables.

11.C Apply checklists

Before submitting the draft report to EERE, the evaluator should cross-check the report against Tables II.10-2 through II.10-5, and rectify any deficiencies and missing parts. Table II.11-2 provides a contents checklist; Table II.11-3, a format checklist; Table II.11-4, a presentation checklist; and Table II.11-5, a process checklist.

The checklists are for use by: evaluators and DOE project managers on an on-going basis to keep the report development on track.

Upon receiving the submitted draft report, the DOE evaluation project manager should compare the report against the four tabular checklists to verify that key features are present. This should be done before the draft report is sent to internal and external reviewers.

Table II.11-1 Uniform Tabular Format for Reporting Summary Evaluation Results from EERE Portfolio Investment

Metric	Unit of Measure	Retrospective Analysis through Year X			Extended Analysis through Year Y (to reflect remaining EUL in the highest level of analysis)
		<u>Level 1</u> Energy and other resource benefits	<u>Level 2</u> Combined Level 1 & environ-mental health benefits	<u>Level 3</u> Combined Level 2 & environ-mental GHG reductions	
Economic Impacts					
Overall Economic Performance Resulting from EERE's Investments					
Portfolio Investment Cost (undiscounted)	Million, constant $				
Gross Benefits (undiscounted)	Million, constant $				
Net Benefits (undiscounted)	Million, constant $				
Net present value @ 7%	Million, constant $				

(Continued)

Net present value @ 3%	Million, constant $				
Benefit-to-cost ratio @7%	Ratio				
Benefit-to-cost ratio @3%	Ratio				
Internal rate of return	%				
Monetary Value of Energy and Other Resource Impacts, and of Environmental Impacts Resulting from EERE's Investments					
Monetary value of energy and other resource impacts	Million, constant $				
Monetary value of greenhouse gas emissions reduction	Million, constant $				
Monetary value of avoided adverse health incidence due to air emissions	Million, constant $				
Energy and Other Resource Impacts, in Physical Units, Resulting from EERE's Investments					
Energy Impacts (saved or installed/ generated)	Btu, type of fuel aved, MW, kWh, gallons				
Other Resource Impacts (e.g., Changes in land resource use)	Relevant units				
Environmental Impacts in Physical Units Resulting from EERE's Investments					
Avoided Air Emissions					
Avoided greenhouse gas emissions in CO_2e (carbon dioxide emissions (CO_2) or equivalents – e.g., methane (CH_4), and nitrous oxide (N_2O))	Metric tons ($MMTCO_2e$)				
Avoided nitrogen oxides (NO_x)	Short tons				
Avoided particulate matter emissions ($PM_{2.5}$)	Short tons				
Avoided sulfur dioxide emissions (SO_2)	Short tons				
Carbon monoxide (CO)	Short tons				

(Continued)

Volatile organic compounds (VOC)	Short tons				
Ammonia (NH_3)	Short tons				
Changes in water consumptions and discharges; and solid waste generation	Relevant units				
Health Impacts in Physical Units					
Avoided mortality	Adult Deaths				
Avoided infant mortality	Infant Deaths				
Avoided nonfatal heart attacks	Attacks				
Avoided resp. hospital admissions.	Admissions				
Avoided CDV hospital admissions	Admissions				
Avoided acute bronchitis	Cases				
Avoided upper respiratory symptoms	Episodes				
Avoided lower respiratory symptoms	Episodes				
Avoided asthma ER visits	Visits				
Avoided MRAD	Incidences				
Avoided work loss days	Days				
Avoided asthma exacerbations	Episodes				
Energy Security Impacts Resulting from EERE's Investments					
Avoided petroleum consumption	Gallons of gasoline equivalent				
Avoided foreign petroleum consumption	Barrels of imported oil				
Reduced vulnerability of U.S. energy infrastructure	Qualitative				
Knowledge Created and Disseminated Resulting from EERE's Investments					
EERE-attributed patents issued	Number of patents				
Patent citations	Citation rates, Citation Index (CI) Value				

(Continued)

DOE patent citation rank among organizations in the field	Rank				
Optional Knowledge Measures					
Knowledge spillovers	Linkages to other technologies, industries, and organizations outside the targeted areas				
EERE-attributed publications	Number of publications				
EERE publications most cited by other publications	Listing				
Publication citations by patents	Citation rates of publications by patents				
Technology Acceleration (as applicable) Resulting from EERE's Investments					
Acceleration effect	Number of years				

Table II.11-2 Contents Checklist

Content topic	Check mark, if completed
• Benefit-cost framework	☐
• Portfolio approach	☐
• Definition of portfolio and explanation of why it was selected	☐
• Description of EERE role and rationale, goals, strategies, and activities in the context of a logic model for the portfolio	☐
• Identification of individual technologies selected from the portfolio for in-depth analysis and the reason for their selection	☐
• Characterization of the technologies selected for in-depth analysis and of the remainder of the portfolio as well	☐
• Characterization of the technological and market contexts within which EERE's investments are made	☐

(Continued)

• Timeline of relevant developments	☐
• Portfolio investment cost table showing year-by-year expenditures in current and constant dollars	☐
• Four categories of benefits presented (as applicable), energy and other resource impacts, environmental health benefits, GHG reduction benefits, energy security benefits, and knowledge benefits	☐
• Impact measures stated in constant dollars, physical units, or qualitatively, as required by Steps 1-6 of the Guide	☐
• Up to 3 levels of retrospective analysis (Level 1, Level 2, Level 3)	☐
• Separate extended evaluation taking into account remaining EUL benefits in each level of analysis	☐
• Measures of social return on EERE investment, including NB, NPV, BCR, and IRR	☐
• Discounting using rates of 0%, 3%, and 7% in calculating PVs, NPVs and BCRs and in comparing against IRR, with 7% results designated as primary for testing economic performance	☐
• Appropriate designation of next-best alternative for comparing the selected technologies depending on whether they are product technologies, technology platforms, or infratechnologies	☐
• Most robust feasible approach used to assess additionality, with first preference to experimental and quasi-experimental designs, and second preference to nonexperimental design approaches using a counterfactual approach	☐
• In a non-RCT research design is employed, explicitly identify the major rival explanatory factors to be addressed in the analysis	☐
• Strengthening of nonexperimental approaches by avoiding biases in expert selection, by briefing experts on context and plausible rival explanations of outcomes, by using a Delphi-type approach to move closer to consensus opinion, by having experts complete a documented attribution matrix, and by using a systematic interview or survey approach to gather data from participants	☐
• Summary of evidence-based findings	☐
• Identification of uncertainties and sensitivity analysis	☐

(Continued)

• Identification of study limitations	☐
• Adherence to all standards and conventions for consistency given in the Guide	☐
• Qualitative treatment of parts of the portfolio not selected for detailed analysis	☐
• Use of valid protocols and procedures in data collection	☐
• Systematic and transparent analyses, with all data, assumptions, and calculations documented and presented, and results replicable	☐
• Explanation of why findings are conservative, lower-bound estimates	☐
• Inclusion of interview and survey tools in an appendix	☐
• Formative results and rationales	☐
• Lay out the following contents concerning the evaluator's actual implementation of study method and data collection o Research questions o Research design o Study population o Data collection o Analysis o Limitations	☐

Table II.11-3 Format Checklist

Element	Required Characteristics	Check mark (if completed)
Title Page	• Title • Date • Prepared by	☐ ☐ ☐
Preface (if desired by DOE)	• DOE prepared description of mission, objectives, programs, rationale for public investment, and purposes of retrospective impact evaluation	☐
Acknowledgements	• Contributors and reviewers, with separate listings of internal and external reviewers	☐
Notice	• DOE prepared notice	☐
Executive Summary	• Written for audiences of diversion backgrounds • Designed to communicate quickly and concisely the most important findings, and implications • Overall results summation • Specific inclusion of Uniform Tabular Format for Reporting Summary Results	☐ ☐ ☐ ☐
Table of Contents and lists of Tables and Figures	• 3-levels of headings for Table of Contents • Headings electronically keyed to report sections to facilitate easy movement by the reader through the report.	☐ ☐

Main Body of the Report	• All elements of essential contents as outlined in Table II.11-2Overview of analysis method and data collection, describing actual implementation of study method and data collection
	• Separate sections on each of the 4 categories of impact that apply to a given evaluation study:
	  ○ Energy and other resource impacts
	  ○ Environmental health impact s and impact s from reductions in GHG emissions
	  ○ Energy security impact s
	  ○ Knowledge impact s
	• Separate section on extended analysis to take into account remaining EUL
	• Separate section on sensitivity analysis
		☐
		☐
		☐
		☐
		☐

References	• List of all references cited in the report (not a general reading list), with clear and concise documentation that allow locating all references	☐

(Continued)

Appendices/Attachments	• Supporting information strongly germane to the presentation, but that can be moved out of the main body of the report for improved readability	☐
List of Terms, List of Abbreviations	• After the list of figures in the front of the report	☐
Index	• Discretionary	☐

Table II.11-4 Presentation Checklist

Essential Characteristics	Check mark (if completed)
• Concise, clear, transparent exposition	☐
• Rigor demonstrated in data collection, analyses, and interpretation	☐
• Presentation accurate and reliable; free of errors of fact or logic	☐
• Findings objectively derived, testable, and reproducible	☐
• Credibility of study among stakeholders	☐

Table II.11-5 Process Checklist

Peer review of study	Check mark (if completed)
• Evaluation plan, with emphasis on Steps 2 and 3, is peer reviewed internally by EERE staff and externally by at least three independent experts	☐
• Evaluator responds to major comments on evaluation plan, and prepares a summary of responses to provide to reviewers	☐
• Full draft report is peer reviewed internally by EERE staff and externally by at least three independent experts	☐
• Evaluator responds to major comments on draft report, and prepares a summary of responses to provide to reviewers	☐

II.12 Document All Input Data, Assumptions, Calculations, and Results

12. Document All Input Data, Assumptions, Calculations, and Results

- Facilitate data quality, transparency, and reproducibility of results by improving documentation.
- Document data sources, assumptions, and calculations.
- Make it possible for a third party with a reasonable level of effort to replicate result.

12.A Facilitate data quality, transparency, and reproducibility of results by improving documentation

The evaluator is contractually responsible for a study's data quality, documentation, transparency, and the reproducibility of results. To allow an effective review, the data quality, documentation, transparency, and reproducibility requirements apply to both the final draft report and to the final report. In support of achieving this standard, the evaluator is required to deliver not just the report, but also data and analysis tables in spreadsheet, suitable for reviewer use in verifying that the results conform to standards and can be easily replicated. Thus, the final deliverables from the contractor include:

- Evaluation study report, and
- Data and analysis tables in spreadsheet.

To emphasize the importance of this requirement, reports that do not comply will be returned to the contractor for additional work. If there are issues of proprietorship regarding data contained within the report or contractor spreadsheets, special arrangements will be made to protect data while enabling the review and checking of results.

12.B Document data sources, assumptions, and calculations

The evaluator should make the analysis process sufficiently transparent that those who read the report can understand the data sources, assumptions, and calculations. Table II.12-1, drawn from the evaluation report on EERE's investment in advanced engine combustion, illustrates that the simple use of table notes to document data and explain calculations.

Table II.12-1 Illustration of Documenting Data and Calculation Steps by the Use of Table Notes

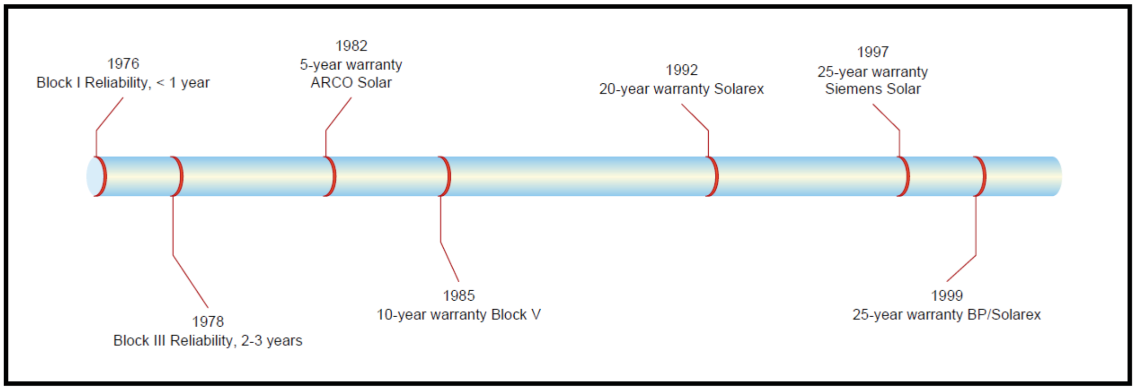
(1) Year	(2) VTP Budget	(3) ACE R&D Sub-Program Budget	(4) CRF Budget*	(5) GDP Implicit Price Deflator (2005=100)	(6) GDP Implicit Price Deflator (2008=100)	(7) Inflation-Adjusted ACE R&D Sub-Program Budget ($2008)	(8) Inflation-Adjusted CRF Budget ($2008)
1976	$12.540			35.489	32.714		
1977	$28.425			37.751	34.799		
1978	$63.798**			40.400	37.241		
1979	$99.170			43.761	40.339		
1980	$110.500			47.751	44.017		
1981	$105.050			52.225	48.141		
1982	$58.944			55.412	51.079		
1983	$53.856			57.603	53.099		
1984	$64.900			59.766	55.093		
1985	$61.772			61.576	56.761		
1986	$57.457	*$15.897****	$3.250	62.937	58.016	$27.402	$5.602
1987	$55.393	*$17.316****	$3.540	64.764	59.700	$29.005	$5.930
1988	$51.360	*$17.157****	*$3.508**	66.988	61.750	$27.785	$5.680
1989	$54.330	*$16.998****	$3.475	69.518	64.082	$26.525	$5.423
1990	$68.394	$17.257	$3.719	72.201	66.555	$25.929	$5.588
1991	$83.564	$15.760	$4.300	74.760	68.914	$22.869	$6.240
1992	$109.282	$16.657	$4.390	76.533	70.548	$23.611	$6.223
1993	$138.632	$14.818	$4.379	78.224	72.107	$20.550	$6.073
1994	$177.249	$12.949	$4.171	79.872	73.626	$17.587	$5.665
1995	$191.065	$10.440	$4.171	81.536	75.160	$13.890	$5.549
1996	$174.288	$16.524	*$4.714**	83.088	76.591	$21.574	$6.154
1997	$172.457	$19.263	$5.256	84.555	77.943	$24.714	$6.743
1998	$189.972	$18.318	$5.161	85.511	78.824	$23.239	$6.547
1999	$198.665	$36.976	$5.024	86.768	79.983	$46.230	$6.281
2000	$228.756	$46.750	$4.736	88.647	81.715	$57.211	$5.796
2001	$251.462	$52.205	$5.463	90.650	83.561	$62.475	$6.538
2002	$181.352	$47.160	$5.377	92.118	84.915	$55.538	$6.332
2003	$174.171	$55.267	$5.935	94.100	86.742	$63.714	$6.842
2004	$172.395	$52.736	$5.892	96.770	89.203	$59.119	$6.605
2005	$161.326	$48.480	$6.437	100	92.180	$52.593	$6.983

(Continued)

2006	$178.351	$40.594	$6.251	103.257	95.183	$42.649	$6.567
2007	$183.580	$48.346	$7.648	106.214	97.908	$49.379	$7.811
2008	$208.359	$43.443	$6.755	108.483	100	$43.443	$6.755

Notes:
When data are not available for a particular year/program, the cell is blank.
* Two years of CRF construction began in 1978, with early years of operation beginning in 1980 through 1985. The complete funding information for those years is unknown.
** denotes values that were constructed as the average for the juxtaposed years.
*** denotes values that were constructed on the basis of the average ratio of the CRF budget to the ACE R&D sub-program budget for all available years.
Column (4) represents DOE Office of Science funding for cross-cutting research programs that are related to combustion and that are within the CRF.
Column (6) = Column (5) / (108.483 / 100).
Column (7) = Column (3) / (Column (6) / 100).
Column (8) = Column (4) / (Column (6) / 100).
Year 2008 shown to benchmark the GDP deflator in Column (6).
Sources:
Nominal budget data in Columns (2) – (4) provided by EERE.
GDP Implicit Price Deflator (2005=100) from U.S. DoC (2009).

Another example from a previous EERE retrospective impact evaluation—this one for EERE solar photovoltaic portfolio—shows the use of supporting evidence to back up a study's assumption. The study makes the case that companies substantially increased photovoltaic module warranties over the evaluation period as module performance improved. Warranty extension is illustrated in Figure II.12-1. Also, note that, as in the preceding example, the data sources are given, and detailed references are included elsewhere in the report for use in locating the source documents.



Sources: Christensen (1985); Green (2005).

Figure II.12-1 Illustration of the Use of Supporting Timelines to Support Underlying Assumptions (drawn by O'Connor et al., 2010, Fig. 5-1)

12.C Make it possible for a third party with a reasonable level of effort to replicate results

In addition to the published final study report, evaluators are expected to provide EERE tables containing input data and calculations electronically in spreadsheet. These data tables should be suitable for review by reviewers to estimate all benefits (including intermediate impacts) and to calculate economic performance measures.

Data input into the spreadsheet from an external source should be labeled as such and the external source should be clearly documented.

Also, the analysis must be fully replicable from tables, figures, formulae, and text presented in the report, and readers will expect to be able to follow all calculations.

II.13 Use Study Findings to Inform EERE Decision Making and for Effective Communications

13. Use Study Findings to Inform Decision Making and for Effective Communications

- Develop a strategy for using study findings in communications with stakeholders.
- Apply relevant study findings to inform EERE decisions.

13.A Develop a strategy for using study findings in communications with stakeholders

In collaboration with evaluators, EERE program staff is encouraged to develop and implement a plan for using its studies to improve communications with stakeholders. The objective is to get the most from the impact evaluations. Related activities may include the following:

- Prepare a one-to-two page "highlights" handout (e.g., an Executive Brief) that provides an overview of the study findings, suitable for distributing both inside and outside DOE.
- Hold a seminar with the Program Office and other EERE staff to allow evaluators to present the study's impact results first-hand, and also to discuss the implications of the formative analysis.
- Prepare briefing points for EERE Management for use in presentations.

13.B Apply relevant study findings to inform EERE decisions

EERE program staff should consider how a given retrospective impact study informs EERE decisions, referring both to the summative results and the additional formative analysis provided by Step 10. The staff is encouraged to look beyond the evaluator's deductions to see if other inferences or insights that inform future investments can be drawn from a study, based on their first-hand perspectives.

II.14 Implement Routine Tracking and Compilation of Data to Support Future Study Updates

14. Implement Routine Tracking and Compilation of Data to Support Future Study Updates

- Implement routine data collection in support of evaluation.
- Maintain records of information that could be used to support future evaluations.
- Consider additional data collection

Data compilation by EERE programs on a routine basis is a cost-effective way to support a program's monitoring and evaluation effort. Without this support, evaluators must later attempt to recreate information that would have been more straight-forward and more reliable to collect by the EERE in real time. Thus, the lack of routine data collection adds to the time and cost of generating performance metrics and evaluation impact results, while increasing the uncertainty of results. The following are recommendations for EERE for (1) a minimum level of EERE program data collection, and (2) extended data collection.

14.A Implement routine data collection in support of evaluation

EERE program staff are expected to collect certain data via the grantee reporting forms. These may include data amenable to routine collection via Funding Opportunity Announcement (FOA) reporting requirements. Data amenable to routine collection should be collected even before an evaluation is initiated, so it will be available when needed. For certain data (see Table II.14-1) this may already be part of the routine collection supported by EERE’s project data collection systems. In addition to routine data collection by EERE staff, it is expected that the evaluator will also be responsible collecting other data needed for a given evaluation study. The evaluator may collect primary data via surveys and interviews, and secondary data from other databases, published reports, or by other collection mechanisms.

After an evaluation is concluded, EERE program staff should consult with the evaluator to determine if any new data, not previously identified (see below) is recommended for routine collection by EERE for future evaluations of the portfolio or program.

14.B Maintain records of information that could be used to support future evaluations

EERE programs and subprograms at a minimum should maintain the following records of information in a format readily available for internal data reporting and for transfer to outside evaluators who are engaged to conduct impact studies:[68]

- Annual expenditures on main program activities and major technology categories. These data will be helpful in defining portfolios for evaluation and are necessary for calculating ROI metrics. The data should be available for provision to evaluators near the outset of a study.
- Records of EERE-funded program partnerships, including identities of the funded companies and other participating organizations by name, address, and contact information; years of funding and yearly funding amount; main partnership objectives and accomplishments; and list of outputs resulting from EERE's support, such as publications, patents filed and granted, patents licensed, products under development including research and production prototypes, sales and sales revenue (if available), and jobs created or retained as a result of EERE's support; achievement of larger technical and market goals; and identification of issues and outlook.
- Records of EERE-funded university programs that identify the funded universities by name, branch, address, and contact information; give the yearly funding amount and identify main objectives of funded programs; and list outputs including publications, patents filed and granted, patents licensed, and spin-out companies.
- Records of in-house EERE research outputs, including publications, patents filed and granted, patents licensed, and other relevant outputs, including those of DOE laboratories managed by other organizations.
- Cost and use records for special DOE facilities closely related to major EERE technology development efforts.
- Data on other relevant DOE collaborative activities with other government agencies, industry-government consortia, industry associations, and other organizations.

In addition to providing needed data for evaluators, these data would allow the EERE programs consistently to provide progress metrics and monitor early outcomes.

Another area that may merit routine data compilation is the management of research grant applications, review, and award administration. Application and award ranking information for grantees and non-grantees might make it possible to perform a R&D impact evaluation that uses a quasi-experimental research design — by establishing a comparison group. One example of when a quasi-experimental design could be performed in the R&D evaluation context, is when it is feasible to identify firms who receive DOE R&D funding awards as well as firms who applied but were rejected because funding was not available for them (i.e., they were nearly as qualified in their proposed research as those who were awarded funds, but just missed the cutoff). Those just missing the award cutoff could comprise a comparison group to enable a quasi-experimental design to

[68] Some of the recommended data collection will be done as part of EERE FOA reporting requirements starting in 2015.

proceed as the design method, following the principles delineated in Section 2B.1-4.

Patents and publications attributed to EERE programs could also be routinely collected in EERE annual project progress report or national laboratory reports. It should be noted that all EERE-attributed publications and patents at the time of an evaluation study may not have yet been entered into existing agency-wide databases, such as the Office of Science and Technology Information (OSTI) database. Furthermore, it may be difficult to determine which publications and patents in a database are attributable to a specific EERE portfolio without special notation. In addition, some patents may be missed in searches of national and international patent databases because organizations funded by EERE do not always give credit in the patent section entitled “Government Interest,” or, if they do, it may be given at a level that is not identifiable as having been funded by a specific EERE program. When these data are compiled at the program or subprogram level it is easier to link outputs to funding by specific EERE programs and portfolios selected for evaluation—particularly data for companies and other organizations which may have filed patents or published following direct interaction with EERE.

14.C Consider additional data collection

The following types of data are also recommended in support of evaluation:

Baseline Documentation: Impact evaluations generally require baselines against which to assess change. However, as indicated in Step 2, defining a baseline is often more complex than simply establishing performance data just prior to the EERE investment. The next-best alternative may change over time, such that dynamic modeling is needed. Moreover, the alternative may best be represented as a counterfactual scenario.

Retrospective impact evaluations are generally conducted some years after a program activity begins. Evaluators are often trying to reconstruct a baseline or alternative scenario some years after the fact. Program efforts to document conditions just prior to or near the start of an EERE's program will be helpful to later impact evaluations.

Early and Intermediate Outcomes Data: These data generally come from those outside the program and often with a considerable lag after program funding. Unless funding arrangements include a requirement that funded companies agree to participate in routine surveys and interviews or other reporting arrangements, it may prove difficult to obtain post-project early and intermediate outcomes data. Thus, it is recommended, if feasible and allowable by DOE and OMB, to include routine data reporting requirements in funding partnerships with others. The program may arrange for web-based or other survey approach to assess post-project developments, or it may interview firms to obtain post-project data. This effort would focus on an on-going collection of output data from funded firms, such as data on patents granted, formation of spin-out companies, jobs created and retained, and product development and sales.

Compilation of, or Linkages to, Relevant Industry and Market Data: Although specific data needed to conduct impact studies will vary by technology and study approach, the need for industry and market data is highly likely. A program may compile industry or market data, or obtain data from other sources, such as by linking to other databases of industry associations, or collecting relevant market studies provided commercially.

In-house data collection is invaluable to evaluation, but is difficult or impossible to anticipate all data that will be required to conduct a retrospective impact evaluation, such as is the subject of this Guide. Knowing the key variables for calculating retrospectively, for example, the fuel savings attributable to a new laser research tool to be used in advanced combustion engine technology would likely have been difficult at the outset of the R&D. It took ex post interviews of an experienced evaluator working with EERE experts to figure out a measurement strategy, followed by econometric modeling to work from available data to the data needed for impact measurement. Further, it was not known in advance that this research tool would become part of an EERE portfolio slated for evaluation, and it was not known that it would be selected for detailed analysis. This observation is made simply to recognize that there generally are limits to in-house data collection in support of impact evaluations. Table II.14-1 is provided in support of EERE's on-going effort to develop an effective data collection infrastructure.

Table II.14-1 Data to Support R&D Portfolio Impact Evaluations

Cost data
• Total yearly program budget • Subprogram level budget • Key activity budget • Breakdown by specific technology areas (e.g., for VTP energy storage R&D study the breakdown might be by NiMH, Li-ion research, other)
Sponsored-partner data
• Sponsored performing organization, amount of funding, dates of funding • Organization lead's name • Organization location • Organization lead's contact information • FOA number • Partner cost share amount • Partner cost share type (cash, in-kind) • Type of funding award (e.g., Cooperative agreement, contract, interagency, grant, other)
Project data
• Project title • Statement of project objectives • Project description • Project location • Project's performing organization • Project Officer name and contact information • DOE HQ project technical manager • DOE HQ project technical manager contact information • Total project funding by year • Cumulative project spending over project life up to current year • Project start date • Project actual completion date • Project planned completion date • Project milestone titles • Project milestones' completion status by title • Project cancelation/ termination date and cause • Project's technology focus area(s) (e.g., for vehicle energy storage areas might be Li-ion, NiMH) • Project's primary research area focus (e.g., for VTP energy storage, is funded R&D focused on Batteries – High Energy, improved power, Improved Life and Abuse Tolerance, Ultracapacitors, materials, or New Tools and Techniques) • RDDD phase • Technology Readiness Level (TRL) status

(Continued)

Relational data
• Role in the value chain (e.g., supplier, manufacturer, system integrator, distributor, service provider, end user, R&D organization, financier, multiple roles, other) • Addition of any new suppliers as part of a DOE grant?
Intellectual property data
• Title of patent awarded for EERE-attributed research in a specified technology area • Patent number • Patent date • Patent assignee • Licensing agreement title • Licensing agreement date • Licensing agreement assignees • Title of publications of EERE-attributed research in a specified technology area • Publication date • Publication authors
Technical achievements data
• Current status of technology development • Technology development goals/ planned technology development • Other research accomplishments • Technology development milestones • Technology durability/ reliability • Technology efficiency • Current Next-Best Alternative (NBA) technology • NBA technology development historical milestones • NBA technology cost • NBA technology durability/ reliability • NBA technology efficiency
Self-reported outside awards, recognition, and achievements (reported by funded partners and others) * NOTE: Further analysis of data is required to assess EERE's contribution
• Name of commercialized technology • Year technology commercialized • Technology developer or co-developers • Other commercialized technology partners • Commercialized technology seller • Promulgated efficiency standards • Growth in Market Share • Sales data • Energy saved • Renewable Capacity Increase (e.g., MWs) • Licensing/Royalty Revenue

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Attachment 1

Drivers for Public Accountability

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

Executive Orders and OMB Memorandum:

- OMB Memorandum to the Heads of Executive Departments and Agencies, July 26, 2013 (Memo M-13-17) **— next steps in the evidence and innovation agenda.** http://www.whitehouse.gov/sites/default/files/omb/memoranda/2013/m-13-17.pdf

- OMB Memorandum to the Heads of Executive Departments and Agencies, May 18, 2012 (Memo M-12-14) **— use of evidence and evaluation in the 2014 budget.** http://www.whitehouse.gov/sites/default/files/memoranda/2012/m-12-14.pdf

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- 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/...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

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Attachment 2

Technology Readiness Levels

	Technology Readiness Level Definition (US DOE EERE)
TRL 1	**Basic Research:** Initial scientific research begins. Focus is on fundamental understanding of a material or process.
TRL 2	**Applied Research:** Initial practical applications are identified. Potential of material or process to satisfy a technology need is confirmed.
TRL 3	**Critical Function or Proof of Concept Established:** Applied research continues and early stage development begins. Includes studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology.
TRL 4	**Lab Testing/Validation of Alpha Prototype Component/Process:** Design, development and lab testing of technological components are performed. Results provide evidence that applicable component/process performance targets may be attainable based on projected or modeled systems.
TRL 5	**Laboratory Testing of Integrated/Semi-Integrated:** Component and/or process validation in relevant environment (beta prototype component level).
TRL 6	**Prototype System Verified:** System/process prototype demonstration in an operational environment (beta prototype system level).
TRL 7	**Integrated Pilot System Demonstrated:** System/process prototype demonstration in an operational environment (integrated pilot system level).
TRL 8	**System Incorporated in Commercial Design:** Actual system/process completed and qualified through test and demonstration (pre-commercial demonstration).
TRL 9	**System Proven and Ready for Full Commercial Deployment:** Actual system proven through successful operations in operating environment, and ready for full commercial deployment.

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