Overview of Evaluation Methods for R&D Programs

A Directory of Evaluation Methods Relevant to Technology Development Programs

Prepared for

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by

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Energy Efficiency and Renewable Energy
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Notice

Preface

The aim of this booklet is to provide a starting point for managers to become aware of and access the best evaluation methods for their needs.

Technology development programs in DOE extensively and successfully utilize peer review to evaluate research and development (R&D) activities at the project and program levels. In addition to peer review, R&D Program Managers are encouraged to use other evaluation methods in order to obtain information on program effectiveness and realized benefits that cannot be provided using the peer review method.

The potential benefits of periodically doing systematic studies using other R&D evaluation methods are considerable. Programs could:

- Generate additional important information for use in continuous program improvement
- Document knowledge benefits that are often unaccounted for when communicating programs' value to stakeholders
- Document realized market benefits associated with past research successes
- Better answer questions about cost-effectiveness of the longer term research

This booklet provides an overview of 14 evaluation methods that have proven useful to R&D program managers in Federal agencies. Each method is briefly defined, its uses are explained, its limitations are listed, examples of successful use by other R&D managers are provided, and references are given. The examples are for successful applications of the R&D evaluation methods taken from evaluation reports by organizations such as DOE's Office of Energy Efficiency and Renewable Energy, DOE's Office of Science, the National Science Foundation, the National Institute of Standards and Technology, and the National Research Council.

The questions a program could ask and answer and the multiple lines of evidence generated by using a variety of R&D evaluation methods would improve program planning and implementation and strengthen the defense of programs with OMB and Congress.

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Part I. R&D Evaluation and Its Benefits

1.1 Increasing Program Manager Information on Program Performance

R&D program managers are close to the projects and activities that make up their programs. They typically are able to relate the ins-and-outs and smallest details to others. They work hard to make their programs succeed. Yet, they may lack information in the form needed to describe and document the benefits their programs are producing -- particularly in the interim period after their direct involvement with projects and other program activities ends and in the longer run when knowledge and/or market impacts are achieved.

Program managers may need to know,

- If their research is being done right (e.g., has high quality and research efficiency)
- If the program's R&D efforts are focused on the right research areas.
- How program-created knowledge finds varied applications that generate additional benefits to the nation.
- How collaborations and other activities stimulated by the program have affected the nation's R&D capabilities.
- How their programs are providing benefits to the users of resulting energy-saving and energy-producing innovations.
- How their programs are enhancing energy security by providing alternative energy sources, protecting existing sources and having options ready for deployment if warranted by changing circumstances.
- If their past efforts were worth it and if planned new initiatives will be worth it.

Having this information when it is needed is essential to the long-run success of their programs.

Evaluation can equip program managers with the information needed to improve their programs and to communicate effectively to others the full range of benefits from R&D efforts. The inability to fully communicate program impacts translates into too few resources for that program. *"The more that those responsible for research can show that they offer value for money, the more credible the case for increased resources becomes."*[1]

The ultimate goal of a technology development R&D manager is to complete research objectives that lead to successfully commercialized technologies. In addition to that ultimate goal, two other goals of a successful program manager are: to continuously improve the program and to communicate effectively to others the benefits of his or her program. These two goals are incorporated into an icon that is used in Part 2 of the booklet to remind program managers about how the various evaluation methods presented can be used to meet their goals.

[1] Luke Georghiou (Professor of Science and Technology Policy and Management, University of Manchester), 2006.

1.2 How this Booklet Can Help You Get the Information You Need

This booklet provides a quick reference guide to evaluation methods for R&D managers in the U.S. Department of Energy's Technology Development programs.[2] While peer review is the form of R&D evaluation most frequently used by R&D managers, there are other evaluation methods which are also useful—particularly for estimating program outcomes and impacts retrospectively. This booklet provides an overview of 14 evaluation methods that have proven useful to R&D program managers in Federal agencies. Each method is briefly defined, its uses are explained, its limitations are listed, examples of its successful use by other R&D managers are provided, and references are given.

The aim is to provide a starting point for managers to become aware of, identify, and access the best evaluation methods for their needs. It is not to provide a comprehensive treatment of the methods or step-by-step guidance on how to do a study using a given method. Rather, the booklet serves the first step in evaluation—determining the kind of study and method that will best serve your needs.

R&D managers interested in pursuing an evaluation study that uses one of the methods described in this booklet can contact evaluation professionals in their organization to get assistance with planning and organizing the study and selecting a reliable independent evaluator to conduct it.[3]

The booklet is organized in two parts. The remainder of this first part provides context for understanding how to select among the various evaluation methods. It presents tables and graphics that together serve as a quick reference roadmap to accessing the methods in the second part. It also presents background information on R&D evaluation. Then, the second part presents overviews of 14 evaluation methods. The methods described in Part 2 of this booklet may be extended at a later time as other new and useful evaluation methods for R&D program managers are identified.

1.3 Why Use a Variety of Evaluation Methods?

The short answer is that it takes a variety of methods to answer different types of project management questions. Furthermore, use of a variety of methods provides multiple "lines of evidence" and multiple lines of evidence often deepen understanding and strengthen arguments. Evaluation is an essential tool for good management practice. It is a tool that not only helps measure a program's success, but also contributes to its success. Evaluation helps managers plan, verify, and communicate what they aim to do, decide how to allocate resources, learn how best to modify or redesign programs, and estimate the resulting program outputs, outcomes, and impacts. Evaluation also provides information for accountability: Did we do what we said we would do?

Peer review/expert judgment, for example, helps a R&D manager answer questions about research quality, relevance, and management. It helps R&D managers learn how to design and redesign program elements and processes, to select projects, to decide whether to continue or discontinue projects, and how best to modify the research direction of the R&D portfolio. Network analysis is

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[2] For example, applied energy R&D programs. Applied research is defined by OMB as the systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.

[3] In EERE, dedicated evaluation staff are located in Office of Planning, Budget and Analysis (OPBA).

useful for answering questions about a program's impact on collaborative research and the dissemination of knowledge—particularly tacit knowledge. Surveys are useful in answering a host of questions, such as how satisfied are the program's customers and how are customers using program outputs. Citation analysis helps document the linkages between a program's outputs and downstream users. Economic case studies can estimate the benefits and costs of program outputs, including those measurable in monetary terms and those more difficult to measure such as environmental effects and energy security effects. Benchmarking can help identify where and how to make improvements by comparing a program with its counterparts abroad. Econometric methods can help demonstrate that it was the program that caused an outcome and not something else. Using these and other methods can help a program manager better understand and manage his or her program so as to achieve its goals, and obtain results needed to communicate achievements to others.

1.4 Use of Evaluation by Federal R&D Agencies

Use of research evaluation in R&D programs—including multiple evaluation methods—is widespread among public science and technology agencies. This was demonstrated in 2002, in a benchmarking workshop in the U.S sponsored by TEKES, the national technology agency of Finland, which compared the evaluation efforts of five U.S. science programs or agencies—National Science Foundation (NSF), National Institute of Health (NIH), the Department of Energy's (DOE's) Office of Science, DOE's EERE, and the National Institute of Standards and Technology's (NIST's) Advanced Technology Program (ATP)—as well as science programs in Canada, Israel, and Finland. The workshop compared these R&D programs in terms of drivers of evaluation, evaluation methods used, obstacles encountered, and other aspects. Table 1-1 shows a benchmarking comparison of the diversity of evaluation methods reportedly used by these organizations as of 2002. You may notice there are opportunities for DOE applied R&D programs to take advantage of the full range of evaluation methods commonly found useful by research programs in Federal agencies.

1.5 Determining Your Specific Evaluation Needs

The key question to ask yourself is "**Who** needs to know **what** about my program and **when**?" You and other program staff are one audience. Senior DOE managers and external parties such as OMB and Congress are among the other audiences. Generally speaking, program managers are interested in information about progress and how to improve programs, while senior managers, OMB staff, and members of Congress are more interested in program outcomes and impacts that can be attributed to a policy and to questions such as "was it worth it?" In DOE's EERE, the current multi-year planning guidance suggests that the program manager have an evaluation strategy that lays out a plan for answering the most important questions for both types of audiences over a period of years.

Table 1-1. Methods of Evaluation Used by the Participating Programs

Methods Used	NSF	NIH	DOE/ OS	DOE/ EERE[4]	ATP	Tekes	IRAP
Surveys	X	X	X	X	X	X	X
Case Study/Impact Analysis	X	X	X	X	X	X	X
Expert Panels, Peer Review, & Focus Groups		X	X	X	X	X	
Indicator Metrics		X	X	X	X	X	
Bibliometrics	X	X	X		X		
Historical Tracing	X	X	X				
Econometrics		X			X	X	
Benchmarking		X	X		X	X	X
Network Analysis			X		X		
Scorecard		X		X		X	
Mission/Outcome Mapping			X				
Options Theory			X				
Foresighting			X				
Composite Performance Rating System					X		
Cost-index method					X		
Market Assessment				X			

Source: Workshop Proceedings, 2002.
Note: Methods used were not identified for Israel's MAGNET program, and this tabulation likely understates the use of methods by Canada's IRAP.

The big questions that require answers can be shown in a very simple diagram of the logic of publicly funded R&D programs, such as that shown in Figure 1-1.

Before defining specific questions, we recommend you review your program's detailed logic with evaluation in mind (or prepare a logic model if you do not already have one). The review can help you identify the most pressing questions and the audiences for the answers.

As the high-level depiction of Figure 1-1 suggests, some questions important for program management occur early in the process, some during the interim period, and others further downstream. Early in the chain, for example, a program manager may wish to track outputs and assess the formation of research relationships using bibliometric and network analysis methods. Later, he or she may wish to conduct a survey to determine industry awareness and use of program outputs. Descriptive case studies may be useful in understanding better the path by which a particular program innovation is adapted by industry and identifying specific barriers that may need to be overcome. A hotspot patent analysis can show whether the patents issued by program researchers are among those heavily cited by others, indicating a burst of interest in the technology area. Farther out, a historical tracing study may tie program research to important industry developments, and an economic cluster study may help quantify dollar benefits of the program's research in a given field. Also farther out, an econometric study may be desired to measure the program's contribution to improvements in the nation's fuel efficiency and to the environment. A

[4] DOE's EERE is primarily an applied research program.

broadly cast benefit-cost study may help to capture a variety of effects, including option benefits that provide protection in the face of possible future developments.

A program's "outcomes" and "impacts" are influenced by many factors beyond a program's control such as private-sector use of the program's outputs, domestic and foreign investment in competing technologies, market prices—such as prices for fuels and other technologies, public policies, laws, and regulations, as well as other factors. Hence, impact evaluations must consider the roles of important external factors on a program's results.

1.6 A Roadmap for Using this Booklet to Broaden Evaluation

The program manager's questions, such as those identified in short-hand form in Figure 1-1 in the context of the high-level R&D Logic Model, drive the choice of evaluation methods. In fact, the variety of recognized evaluation methods have evolved as evaluators have developed ways to address the principal kinds of questions commonly asked by program managers and policy makers. The methods provide their answers using different units of measures, and the desired unit of measure can be an important factor in choosing among the methods. For example, the question posed may ask for statistical measures, best provided by the survey method. The question may ask for numbers of publications or patents, best provided by the bibliometrics methods (counts), or evidence of dissemination of knowledge, best provided by citation analysis or network analysis. The question may ask for financial measures, such as present-value net benefits or rate of return on investment, best provided by economic methods. The question may ask for descriptive and explanatory information or it may probe for understanding of underlying factors, best provided by case studies.

Table 1-2 summarizes seven sequential steps to help R&D Managers get started answering important questions to help achieve program technical and management goals, including a step to guide them to choose the evaluation method(s) to meet their specific needs.

Table 1-2. Summary Steps for Achieving Program Manager Goals through Evaluation

Step 1	Consult the performance logic diagram shown in Figure 1-1 and identify the phase of the program performance cycle on which you wish to focus.
Step 2	Go to Tables 1-3 through 1-6 and find the one for the selected phase of the program performance cycle.
Step 3	Find within column 1 of the table a question or questions that you would like to have answered.
Step 4	Within the same table, go to column 2 to identify the recommended evaluation method and note the number in parentheses. (No.) gives listing order of methods in Part 2 of this document.
Step 5	Within the same table, go to column 3 and confirm that the recommended method will provide a type of measure that will likely meet your need.
Step 6	Go to Part 2 of the booklet and find the write-up for the recommended method.
Step 7	After learning more about the method, read Section 1-7, "Additional Considerations." Then consult with evaluation staff in your organization for further assistance and begin working with an independent evaluator to proceed with a study.

A series of four tables — Tables 1-3 through 1-6, used in conjunction with the R&D Logic Model in Figure 1-1 — guide program managers to choose the evaluation method(s) to meet their specific needs. The tables correspond to four distinct phases of the program performance cycle.[5] Table 1-3 starts with Phase 1, the designing/revising, planning, selecting, and budgeting phase of the program performance cycle. Table 1-4 moves to Phase 2, the phase during which R&D progress is made, process mechanisms are implemented, and program outputs are achieved. Table 1-5 continues to Phase 3, when the outputs are disseminated, technologies are handed off to potential user, and knowledge is acquired by others, during which time the program managers watch for interim outcomes. Table 1-6 shows what happens in Phase 4 and beyond, during which time longer term outcomes and impacts occur, including energy savings, improvements in energy supply, environmental effects, energy security benefits, technology options that may be needed under changing conditions, and knowledge benefits resulting in new and improved products in other industries.

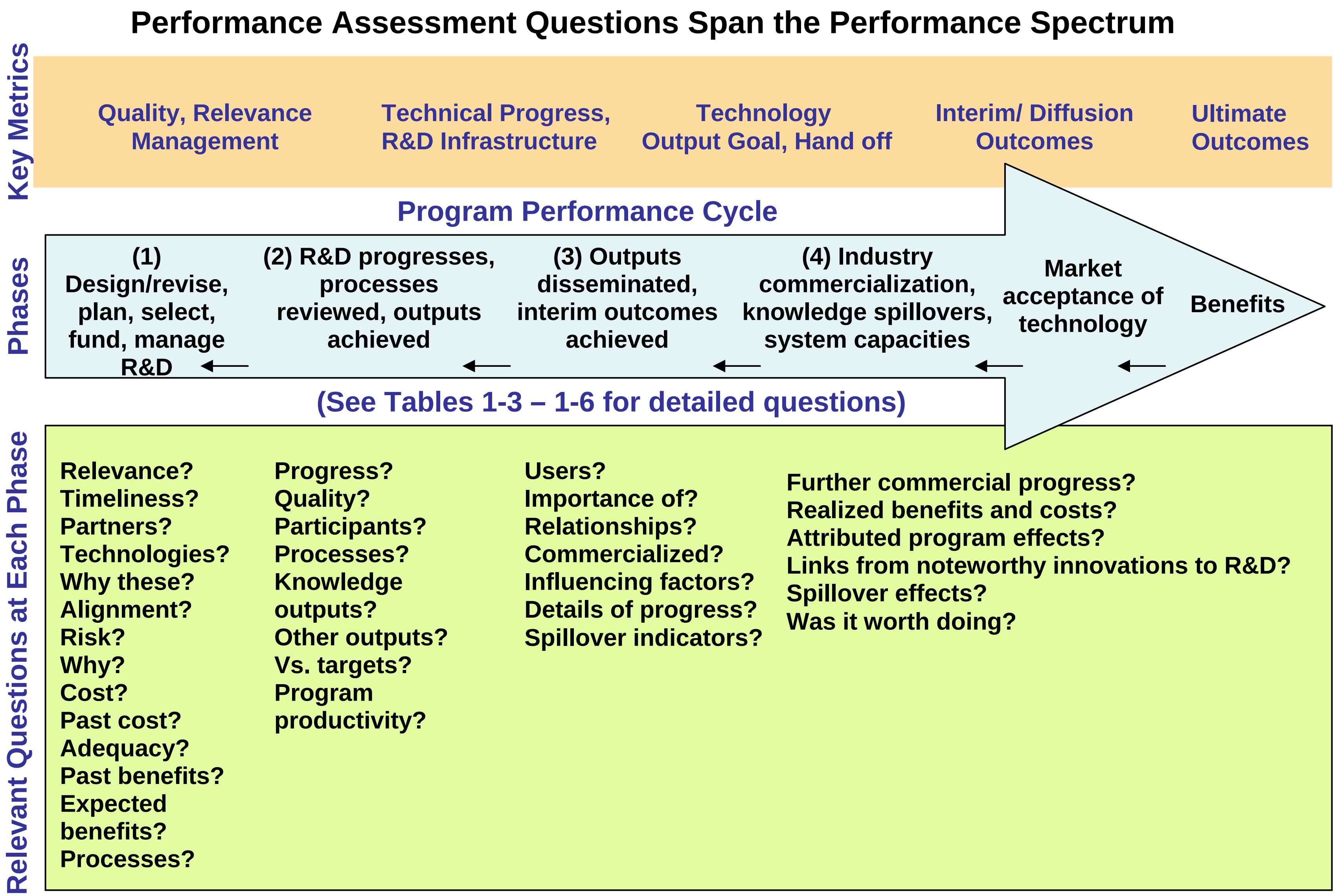
Each of the four tables lists in its first column questions a program manager is likely to encounter during the specified phase of the program performance cycle. Though not exhaustive, the questions listed indicate the kinds of performance questions that are typically asked during each phase. If you, the program manager, do not find your question phrased exactly as you would word it, you should find a question sufficiently similar to allow you to proceed through the Roadmap.

Evaluation methods (identified by name and number) that are used to answer each question are listed in the second column of the tables, linked to the questions. In turn, the types of measures associated with each method are listed in the third column, linked to the methods and questions. Several of the methods and measures occur multiple times because they are useful for answering more than one question. Several of the questions occur more than once because they may need to be revisited as a program progresses.

Figure 1-2 links the four phases of the program performance cycle back to the program manager's goals and lists information provided by different evaluation methods to help meet those goals. This figure is incorporated into an icon used in Part 2 to assist the program manager in selecting the right method for his or her purpose.

[5] It is recognized that the innovation process is nonlinear, but from the perspective of the program manager, it is convenient to portray the program performance cycle as having linear elements.

Figure 1-1. Basic Logic of R&D Programs and Evaluation Questions



[Source: Gretchen Jordan, SNL]

Figure 1-2. Program Manager Goals, Phases of Program Performance, and Evaluation Information Provided by Evaluation Methods.[6]

Program Manager Goals:

- Improve Program
- Communicate why the program is worth doing

Four Phases of Program Performance Cycle:

1. Design/revise, plan, select, budget
2. Make R&D progress, review processes, achieve outputs
3. Disseminate outputs, achieve interim outcomes
4. Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts

Information Provided by Evaluation Methods[a]:

- Planning information[b]
- Indicators of interim progress
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures[c]
- Spillover effects
- Comparative standing[d]
- Overview – was it worth it?[e]

1.7 Additional Considerations in Evaluation

Beyond identifying the questions to be addressed and the evaluation method(s) to be used, there are additional considerations in undertaking evaluation studies. Important among these are the level of effort to be employed; the design requirements of the study; whether the focus is an individual project, a program, a portfolio of projects or programs, a system, or an organization; whether the evaluation is to be performed retrospectively or prospectively; and identifying the audiences for evaluation results. Each of these considerations is discussed briefly in turn.

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[6] Some items in the framework – labeled in alphabetical order – require clarification. The clarifications are as follows: (**a**) The types of information listed are broad categories to which a variety of methods typically can contribute. For example, the survey method has been used to contribute to most, if not all, the informational categories shown, as has the case study method. Similarly, both methods have been used in all or most phases of the program performance cycle. However, when the figure is used as an icon in Part II, the purpose is to highlight for each method the principal type(s) of information it generates and the principal phases in which it is used; (**b**) "Planning information" as used here encompasses a wide range of different types of information, including increased understanding of program dynamics and transformational processes, assessment of technical risks, budget analysis, estimates of user needs and satisfaction, and other information that bears on the operational design of a program; (**c**) "Benefit-cost measures" encompass net present value measures, benefit-to-cost ratio measures, and rate of return measures, including private returns, social returns, and returns attributed to the public investment; (**d**) "Comparative standing" refers to how a program compares with other programs in terms of selected dimensions, for example, the size and growth rate of their research budgets, the educational attainments of their employees, their R&D outputs, and their productivity in generating outputs; (**e**) Overview judgments of a program's worth generally draw on a larger body of information compiled through the use of a variety of evaluation methods.

Level of Effort: The amount of time and resources to be put into an evaluation study can vary depending on the analytical challenges faced, the method(s) used, the complexity of the study design, the data existing and needing to be compiled, the intended use of the results and related need for the study to be carefully researched, documented, defensible, and publishable, and, of course, the program resources available for the study. After a program manager has identified the question(s) to be answered, the intended use of the study, and the audience for the results, a study plan can be developed and study costs estimated based on the method(s) to be used and the desired features of the study.

Study Design: How a study is designed is dependent on the type of question asked. Three common types of questions are (1) descriptive questions, (2) normative questions, and (3) impact or cause and effect questions.[7]

Descriptive questions are generally the easiest to address. These are the what, why, who, how, and how much or how many questions. For example, we may wish to know how many papers were published from 1995 through 2005 by a program. The answer requires a simple count of published papers. Suppose we wish to know what connections exist between a particular government lab, other government labs, universities, and company labs. A network analysis can show the linkages among these organizations. Suppose we want to know who developed a technology and why. The descriptive case study method can tell the story of the developers, their motivations, and critical aspects of the development.

Normative questions are asked when we have a standard, goal or target and we want to know how actual outcomes compare against the standard or goal. Answering this kind of question is also relatively straight-forward. The way the goal or target is expressed determines the method used to answer normative questions. For example, a program goal may be to achieve at least an 85% customer satisfaction rating. Thus, the relevant question is did the program meet its goal of achieving at least an 85% customer satisfaction rating—a question that can be answered using the survey method.

Impact questions require more attention to study design, because the evaluation needs to show not only that an effect can be observed but also that the program in question caused it to happen—although with R&D it is often feasible to show "contribution" rather than strict causality. For a non-R&D example of the challenge of showing causality, consider a program that aims to increase jobs. The program is implemented and employment increases. Was it the program or changes in the business cycle independent of the program that is responsible for the increase? For an R&D example, suppose a program seeks to increase fuel efficiency by developing a new type of engine.

[7] The discussion of types of questions and formulation of study design is based on material from an on-line course on evaluation described by Bill Valdez, Bill Eckert, Padma Karunaratne, and Rosalie Ruegg in a presentation at the 2005 annual meeting of the American Evaluation Association, Toronto Canada, October 2005.

Table 1-3. Phase 1 of Program Performance Cycle: Designing/Revising, Planning, Selecting, and Budgeting

Relevant Questions	Methods for Answering Questions (No.) gives listing order in Part 2	Types of Measures Given
What are the relevancy and timeliness of this program or initiative? Would it make sense to delay it until more fundamental work on enabling technologies is completed? What are the factors that endanger it?	(2-1) Peer review/Expert judgment in support of strategic planning, selecting, and budgeting	▪ Judgment ▪ Critiques ▪ Recommendations
Who are your partners, and how much are they contributing to the effort?		
What technologies (or other outcomes) do you expect to deliver, and when?		
How did you come to select the technologies/approaches you are using in pursuit of the program or initiative?		
How do planned projects or activities support planned program or initiative objectives?		
Does the innovativeness (technical risk level) of the planned R&D program meet acceptable levels?		
Why do you think the technology will work?		
How much will the program/initiative cost? How did you come to this cost estimate? What is the likelihood that this amount will be sufficient to achieve the goals?		
How much has been spent thus far? Does the progress achieved thus far match expectations based on those expenditures?	(2-11) Benefit-cost analysis -- retrospective	▪ Economic, knowledge, environmental, & security benefits
What additional benefits are expected from the new program or initiative relative to its additional costs?	(2-11) Benefit-cost analysis -- prospective	▪ Economic, environmental, & security benefits
Are program mechanisms, processes, and activities appropriate to achieve program or initiative goals? How are resources to be transformed into desired outputs and outcomes? How can the transformational processes be strengthened?	(2-1) Peer review/Expert judgment	▪ Judgment
	(2-7) Case study	▪ Qualitative explanations
	(2-12) Econometric studies	▪ Quantitative functional relationships
Why do you think the planned efforts will yield the results you are seeking? What confidence do you have in our ability to deliver the desired outcome? Why?	(2-1--2-14) All methods	▪ Past and predicted performance results from multiple studies (see tables 3-5)

Table 1-4. Phase 2 of Program Performance Cycle: Making R&D Progress, Reviewing Process Mechanisms and Achieving Outputs

Relevant Questions	**Methods for Answering Questions (No.) gives listing order in Part 2**	**Types of Measures Given**
Are we making technical progress as planned?	(2-2) Monitoring: comparing progress against technical milestones	▪ Comparison of technical achievements against targets
Is the program's research of high scientific quality? Is it relevant, productive, and well managed?	(2-1) Peer review/Expert judgment	▪ Judgment
Who is participating? In what roles? What relationships are developing? Is the program strengthening the research network?	(2-6) Network analysis Before-and-after applications are recommended	▪ Diagram showing connections among research entities
How are program mechanisms, processes, and/or activities working? How can they be strengthened?	(2-2) Monitoring activities	▪ Indicators
	(2-7) Case study -- descriptive/exploratory	▪ Qualitative explanations
	(2-12) Econometric studies	▪ Quantitative functional relationships
What are the program's codified knowledge outputs?	2-3) Bibliometrics – counts	▪ Number of papers ▪ Number of patents
What are other outputs of the program? Do they match expectations?	(2-2) Monitoring outputs	Indicators, e.g., ▪ Number of research prototypes ▪ Number of processes ▪ Number of algorithms ▪ Number of students trained ▪ Comparisons of achieved outputs against targets
How does the program's output productivity compare with similar programs?	(2-9) Benchmarking	▪ Comparison of units of outputs per resource input among programs

Table 1-5. Phase 3 of Program Performance Cycle: Output Dissemination and Achievement of Interim Outcomes

Relevant Questions	Methods for Answering Questions (No.) gives listing order in Part 2	Types of Measures Given
Who is using the program's knowledge outputs? To what extent?	(2-3) Bibliometrics – citation analysis	▪ Citations of publications ▪ Patent citation trees
How noteworthy are the resulting patents? What are the hot trends? Are there important regional impacts?	(2-5) Hot-spot patent analysis	▪ Relative frequency of citations
What role did the program play in initiating research in this area?	(2-4) Bibliometrics – data mining	▪ Growth in use of keywords in documents over time & program's contribution
What additional project-related relationships have developed among researchers? Among others, such as commercializers and users?	(2-6) Network analysis Before-and-after applications are recommended	▪ Diagram showing connections among related entities
To what extent have the program's outputs been commercialized?	(2-2) Indicators (2-10) Technology commercialization tracking	▪ Number of outputs commercialized ▪ Stage of commercialization ▪ Extent of commercialization
What factors are influencing industry's adoption/lack of adoption of the program's technologies?	(2-7) Case study -- descriptive/explanatory	▪ Narrative and data List of factors
How long is it taking to first sales? How much is being realized in annual revenue? What are related employment effects?	(2-8) Survey	▪ Statistics
What are the realized benefits and costs of the technology to date? What share of net benefits from the technology are attributed to the program?	(2-11) Benefit-cost analysis	▪ Net present value benefits with and without the program ▪ Rate of return
What evidence is there of spillovers from the R&D?	(2-14) Spillover analysis	▪ Indicators of spillovers
How is the program working thus far?	(2-7) Case study – descriptive/explanatory	▪ Narrative and data

Table 1-6. Phase 4 of Program Performance Cycle and Beyond: Commercialization, Market Acceptance, Outcomes and Impacts

Relevant Questions	**Methods for Answering Questions (No.) gives listing order in Part 2**	**Types of Measures Given**
To what extent has commercialization been achieved?	(2-10) Technology commercialization tracking (2-8) Survey	▪ Stage of commercialization and extent of commercialization ▪ Statistics on commercial achievements
What are the realized benefits and costs of the program or initiative?	(2-11) Benefit-cost analysis -- retrospective	▪ Economic, knowledge, environmental, & security benefits
What effect has the program or initiative had on residential energy efficiency? On commercial energy efficiency?	(2-8) Survey (2-12) Econometric method	▪ Correlation results ▪ Production functions
Are there one or more noteworthy innovations that can be shown to link back directly to the program's research?	(2-13) Historical tracing (including citation analysis)	▪ Documented path linking downstream innovation to upstream R&D
Is there evidence that knowledge spillovers (use of research results beyond planned uses) have occurred?	(2-3) Bibliometrics – citation analysis (2-6) Network analysis	▪ Citations of publications ▪ Patent citation trees ▪ Diagram showing connections among research entities
What are the spillover effects for consumers and producers in the target industry and in other industries from the program's or initiative's technologies and knowledge outputs?	(2-14) Spillover analysis	▪ Consumer surplus ▪ Producer surplus ▪ Knowledge spillovers ▪ Network spillovers
How does the program compare with counterpart programs?	(2-9) Benchmarking	▪ Comparisons among programs on selected parameters
If we had it to do all over again, would we have launched the program or initiative?	(2-1) Peer review/expert judgment supported by multiple retrospective evaluation methods (2-3--2-14)	▪ Comparison of retrospective evaluation results against original program/initiative expectations

Then fuel efficiency increases. Was it the government research program that caused the efficiency improvement, or was it something else, such as private-sector R&D?

To establish cause-and-effect conditions, an evaluation study needs, first, a logical theory that explains why a causal relationship makes sense. Second, it needs the cause and the effect to follow a logical time order, such that the program precedes the observed outcome. Third, it needs to ensure that the condition of co-variation is met, i.e., the outcome has the ability to change as the program's intervention is applied. And, fourth—and most difficult, the evaluation needs to eliminate rival explanations for the observed changes.

Approaches to help establish causality include before and after comparisons; use of control groups with random assignment; application of statistical/econometric techniques to eliminate rival explanations when comparison groups do not include random assignment; and use of counterfactual questions of participants to try to assess what would have happened if the program had not existed.

Study Focus on Project, Program, or Beyond: It should be noted that with the exception of benchmarking, the methods presented are intended for use within the scope of a given program to evaluate individual projects, related collections (or portfolios) of projects, or, in some cases, a program as a whole. At this time the state-of-the-art of evaluating collections of research portfolios across multiple programs and organizations is limited and under development.

Retrospective versus Prospective Evaluation: Retrospective evaluation takes a look back at past accomplishments. It is based on empirical data. Prospective evaluation projects what is expected to happen in the future. Prospective evaluation is performed to forecast results of a decision too recent to have generated empirical data. Prospective evaluation is characterized by more uncertainty than retrospective evaluation—uncertainty about the technical outcome of a project or program, uncertainty about market acceptance of the technical outcome, and uncertainty about future "states of the world" that may affect demand and supply conditions. Hence, the results of prospective evaluation tend to be more uncertain than the results of retrospective evaluation.

Communicating Evaluation Results to Different Audiences: The program manager will be a prime audience for results of an evaluation study, but there are other "stakeholders" who also may be interested in evaluation results. To reach other stakeholders, to address their specific needs, and to communicate to them the relevant findings, the R&D program staff can help develop an "evaluation results" communications plan.

References

Luke Georghiou, "What Lies Beneath…Avoiding the Risk of Undervaluation," presentation presented at the conference, New Frontiers in Evaluation, Vienna, April 24-25, 2006Fteval. (Available online at www.fteval.at/papers06 by selecting "plenary sessions" and number 3.)

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U.S. Office of Management and Budget, "What Constitutes Strong Evidence of a Program's Effectiveness?" Supporting Materials/References for Program Assessment Rating Tool (PART Guidance, 2004), Executive Office of the President, accessed January 2006 at www.whitehouse.gov/omb/part/2004_program_eval.pdf.

Part II. Overview of Selected Research Evaluation Methods

Each of fourteen evaluation methods is described in sections that comprise Part 2, the heart of the booklet. The treatment of each includes:

- a definition of the method and what it has to offer the program manager;
- an overview of how the method is organized, conducted, and analyzed;
- limitations of the method;
- practical uses of the method; and
- examples.

The examples are for successful applications of the R&D evaluation methods taken from evaluation reports by organizations such as DOE's EERE, DOE's Office of Science, the National Science Foundation, the National Institute of Standards and Technology, and the National Research Council. Note that each example is a brief synopsis taken from a study—in many cases a quite lengthy and detailed study. In order to adhere to the booklet's aim of providing a quick reference and overview, many details of the source studies are omitted. However, references are provided at the end of the presentation of each method for those who wish to delve further into the examples. Many of the full reports from which the examples are drawn are available on-line for easy access.

The methods are presented in the order listed. Their numbers (in parenthesis) refer to the sections that follow, and they are also keyed to the series of questions presented in Tables 1-3 through 1-6. As indicated in the tables, most of the methods are used to answer questions in more than one phase of the cycle. An icon (based on Figure 1-2) at the top of each section alerts the program manager to the phase or phases of the program performance cycle in which the method will likely be most useful and highlights the type of information it will provide.

(2-1) Peer Review/Expert Judgment
(2-2) Monitoring, Data Compilation, and Use of Indicators
(2-3) Bibliometrics – counts and citation analysis
(2-4) Bibliometrics – data mining
(2-5) Bibliometrics – hotspot patent analysis
(2-6) Network Analysis
(2-7) Case Study Method – Exploratory, Descriptive, and Explanatory
(2-8) Survey Method
(2-9) Benchmarking Method
(2-10) Technology Commercialization Tracking Method
(2-11) Benefit-Cost Case Study
(2-12) Econometric Methods
(2-13) Historical Tracing
(2-14) Spillover Analysis

Again, it should be kept in mind that the field of R&D evaluation is still developing. Additional methods and techniques may be added to this booklet as they are developed, tested, and found useful to R&D managers.

2.1 Peer Review/Expert Judgment

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. **Make R&D progress, review processes, achieve outputs**
3. Disseminate outputs, achieve interim outcomes
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- **Planning information**
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- Spillover effects
- Comparative standing
- **Overview – was it worth it?**

[Goals, phases, and information provided by this method are highlighted]

Peer review/expert judgment is a relatively low-cost, fast-to-apply, well-known, widely accepted, and versatile evaluation method that can be used to answer a variety of questions throughout the program performance cycle, as well as in other applications. It is used, for example, for support of strategic planning decisions, selecting among projects and programs, for in-progress project and program review, for process assessment, for stage-gate decisions, for merit review of papers for publications, and for making judgments about diverse topics, including—when supported by results from application of other methods—the overall success of a program. It is widely used by industry, government, and academia. In practice, it ranges from a formal process conducted according to strict protocol to an informal process.

Definition: Peer Review/Expert Judgment is qualitative review, opinion, and advice from experts on the subject being evaluated, based on objective criteria. The method combines program performance information (provided to the experts) with the many years of cumulative experience of the subject-matter experts, and focuses that informed expertise and experience on addressing key questions about a program, initiative, project, proposal, paper, topic, or other subject of focus. While information from other sources, including other methods of evaluation, may provide influential evidence, the ultimate conclusions about performance are based on the judgment of the experts.

EERE's Peer Review Guide (2004) defines in-progress peer review as:

> *A rigorous, formal, and documented evaluation process using objective criteria and qualified and independent reviewers to make a judgment of the technical/ scientific/business merit, the actual or anticipated results, and the productivity and management effectiveness of programs and/or projects.*

How DOE's EERE in-progress peer reviews are organized, conducted, and analyzed: The EERE Peer Review Guide sets out minimum requirements for planning, conducting, and responding to peer reviews. A primary requirement is that the reviews be independent both in fact and in terms of public perception. This is achieved through having processes that are transparent and having third parties involved in the selection of reviewers. To a large extent, the quality of the results depends upon the choice of qualified and independent reviewers. In addition to being experts in the subject matter, reviewers should have no real or perceived conflict of interest. Their judgments should be guided by the objective evaluation criteria, established prior to the review, and should address the specific questions established for the review. When used to review an individual project or a collection of projects, peer review generally focuses on the question *"are we doing it right?"* A program-level review will focus on the broader issue of "*is the program doing the right thing?"*

Limitations: The quality and credibility of peer/expert evaluation is highly dependent on the reviewers/experts selected and the evaluation questions and criteria used by those reviewers. Reviewers must be very knowledgeable about the subject and free of conflict of interests that could bias their judgment. The sometimes-expressed view that peer review is an "old boys club" must be avoided. Steps may be needed to calibrate reviewer ratings. Defining appropriate criteria may be problematic when the work being reviewed is highly innovative. Peer review panels are dependent on sound and detailed information on which to base their judgments about a program's progress or impact, and they are vulnerable to poor and insufficient information. The type of data needed for retrospective impact assessment cannot be created in an expert review panel format. For this reason, peer review tends not to be appropriate for evaluating impacts of programs -- except if a peer review panel is provided substantial, reliable results from impact studies based on other methods, and serves the function of integrating results across multiple studies.

Uses:

- To conduct in-progress reviews of scientific quality and productivity.
- To help answer questions about the relevancy, timeliness, riskiness and management of existing program research activities, and resource sufficiency of new program initiatives.
- To score and rate projects under review to aid decisions to continue, discontinue, or modify existing or planned projects, programs, or program initiatives.
- To help assess appropriateness of program mechanisms, processes, and activities and how they might be strengthened.
- To integrate across multiple evaluation results and render judgments about the overall success of a program or program initiative.

- To provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.

Examples: Two examples are given. The first illustrates DOE's formal use of peer review for in-progress review of projects and program. The second illustrates a less formal, less rigorous use of experts convened as a working group and supported by the results of previously completed studies and specially commissioned papers, to review and discuss several research questions. It is provided to suggest the wide range of practice in using "peers" or "experts" for evaluation.

Example 1: Using in-progress peer review to assess the performance of projects in DOE Hydrogen Program

In the EERE Hydrogen, Fuel Cells, and Infrastructure Technologies Program (HFCIT), research and other activities performed by industry, universities, and national laboratories are evaluated annually at the Hydrogen Program Merit Review and Peer Evaluation meeting. Independent expert panels review the project portfolio in accordance with criteria, which helps guide the program's Technology Development Managers in making funding decisions for the new fiscal year. This review of the HFCIT program is conducted using the process outlined in the EERE Peer Review Guide. In addition to annual peer review at the project portfolio level, external reviews are conducted every two or three years by the National Academies (e.g. National Research Council, National Academy of Sciences), or an equivalent independent group.[8] The program prepares a formal response to the review recommendations.

Table 2-1 illustrates how peer review results were used by the Hydrogen Program to help inform decisions on whether to continue or discontinue research projects.[9] Table 2-1 shows a sample subset of a larger collection of summary results for HFCIT program technical areas in 2003. Many research projects determined to have very low peer review ratings, as established from a comparable peer review process applied to all projects in a given subprogram, were discontinued. A summary of scoring results and Program decisions follows the table.

[8] See, for example, The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs, prepared by the National Research Council (NRC) and National Academy of Engineering. February 2004.
[9] FY2003 Hydrogen Program Merit Review & Peer Evaluation Report.

Table 2-1. Results Summary Table from 2003 HFCIT Program Peer Review Report

Project No.	Project, Performing Organization	Avg. Score	Conti nued	Disconti nued	Comp leted	Summary Content
10	Low Cost H2 Production Platform, Praxair	2.95	V			Emphasize collaboration.
11	Defect-free Thin Film Membranes for H2 Separation & Isolation, SNL	2.87	V			
12	Maximizing Photosynthetic Efficiencies and H2 Production in Microalgal Cultures, UC Berkeley	3.33	V			Focus on program RD&D goals for 2005.
13	Reformer Model Development for Hydrogen Production, JPL	2.27		V		Model analysis in this area is no longer a program requirement.
14	Photoelectrochemical H2 Production, University of Hawaii	3.30	V			Emphasize further development of multi-junction photoelectrodes to meet program RD&D goals for 2005.
15	Photoelectrochemical Water Splitting, NREL	3.23	V			Focus on candidate lighting materials.
16	Encapsulated Metal Hydride for H2 Separation, SRTC	2.83			V	
17	Economic Comparison of Renewable Sources for Vehicular Hydrogen in 2040, DTI	2.90			V	
18	Biomass-Derived H2 from a Thermally Ballasted Gasifier, Iowa State University	2.70	V			
20	Evaluation of Protected Metal Hydride Slurries in a H2 Mini-Grid, TIAX	3.20			V	
22	Novel Compression and Fueling Apparatus to Meet Hydrogen Vehicle Range Requirements, Air Products & Chemicals Inc.	3.20	V			
30	Techno-Economic Analysis of H2 Production by Gasification of Biomass, GTI	2.60			V	Project completed.
31	Supercritical Water Partial Oxidation, GA	2.57		V		Unlikely that cost barrier can be overcome.
32	Development of Efficient and Robust Algal Hydrogen Production Systems, ORNL	3.47	V			Focus on designing new DNA sequence coding for proton channel.
34	Water-Gas Shift Membrane Reactor Studies, University of Pittsburgh	2.90	V			Emphasize feasibility of hi-temp water-gas shift under realistic operating conditions.
38	Low Cost, High Efficiency Reversible FC Systems, Technology Management Inc.	2.80		V		High electrical input requirement prevents overcoming energy efficiency barrier.
39	High-Efficiency Steam Electrolyzer, LLNL	2.37		V		Carbon deposition at anode is a recurring problem.

Source: FY2003 Hydrogen Program Merit Review & Peer Evaluation Report

Peer review scoring results for hydrogen research projects:

- In 2003 there were 56 total hydrogen projects that received a review rating.
- Distribution of scores ranged from 2.2 to 3.68 on a 4-point scale (1.0 to 4.0).
- 8 projects were judged to be "completed."
- 7 projects were discontinued.
- 6 of 7 discontinued projects were at or lower than the 2.8 rating threshold. They were discontinued for the following stated reasons:
    - Model analysis in this area is no longer a program requirement.
    - Project funding was terminated due to poor review.
    - Carbon deposition at anode is a recurring technical problem.
    - It is unlikely that the cost barrier can be overcome.
    - Project funding was terminated pending further review of approach.
- A seventh project had a score of 3.23 but was discontinued for the following reason:
    - High electrical input requirement prevents overcoming barrier.

Peer review scoring results for fuel cell research projects:

- In 2003 there were 73 total fuel cell projects that received a review rating.
- Distribution of scores ranged from 1.8 to 3.9 on a 4-point scale (1.0 to 4.0).
- 15 projects were judged to be "completed" or "concluding."
- 5 projects were discontinued.
- 4 of 5 discontinued projects were at or lower than the 2.8 rating threshold. They were discontinued for the following stated reasons:
    - Project was terminated since other approaches to fuel cell humidification appear to be more effective.
    - Project was halted pending go/no-go decision.
    - Project funding was terminated in favor of higher priority R&D.
    - Project was terminated since technology is unable to meet technical targets.
- A 5th project had a score of 3.04 but a decision was made to set project priorities and focus future continued work only on a critical element of the research.

<u>Example 2: Using expert judgment informed by supporting studies and papers to examine issues surrounding public support of technology development</u>

Researchers at Harvard University's Kennedy School of Government in collaboration with MIT's Sloan School of Management and the Harvard Business School used elements of expert review in conducting a study of barriers to private-sector funding of early-stage, high-risk technology development projects.[10] This study lacked the formality and rigor of the previous example in running a peer review process; it did, however, rely on a group of experienced practitioners from business, finance, and government, together with academic experts, convened in two workshops to discuss commissioned papers, hear presentation, discuss issues surrounding the management of technical risks and related funding decisions, comment on the results of supporting studies, and explore answers to the following questions:

- How do industrial managers make decisions on funding early-stage, high-risk technology projects?

[10] Branscomb et al., 2000.

- What external factors, especially those controlled or influenced by government, can sufficiently reduce the risk factor of projects that appear otherwise to be attractive commercial opportunities for the firm, so that firms will invest in them and seek their commercialization?
- How can a government program better identify projects that would not be pursued or would be pursued less vigorously without public support and at the same time are likely to lead to commercial success—with broad public benefits—with that support?

In attempting to address these questions, the study concluded that there is a serious and widening gap in sources of support for research projects that fall between concept development and the research needed to reduce a technology to practice.

References

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National Research Council (NRC), *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*, prepared by the National Research Council (NRC) and National Academy of Engineering, February 2004.

U.S. DOE EERE, *EERE Peer Review Guide: Based on a Survey of Best Practices for In-Progress Peer Review*, August, 2004.

U.S. DOE EERE, *FY2003 Hydrogen Program Merit Review & Peer Evaluation Report*, 2003.

2.2 Monitoring, Data Compilation, and Use of "Indicators"

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. **Make R&D progress, review processes, achieve outputs**
3. **Disseminate outputs, achieve interim outcomes**
4. Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts

Information Provided by Evaluation Methods:

- **Planning information**
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- Spillover effects
- Comparative standing
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

Monitoring a program as it is carried out, collecting resulting data, and generating selected indicator metrics from the data are integral to evaluation. Pairing monitoring with evaluation is considered good practice. Continuous monitoring and data collection support evaluation and provide useful interim indicators of change in key program functions that can guide program managers in making mid-course corrections.

Definition: Monitoring is a continuous assessment of key program functions organized internally by program management and carried out on an on-going basis. Monitoring entails setting up a data collection system for compiling key data on program activities, participants, interim achievements and outputs. The resulting data can be used to develop interim performance metrics or "indicators" of program progress, outputs, and outcomes, and are helpful in keeping a program on track and for guiding mid-course corrections. The data also contribute to evaluation studies.

How monitoring and data collection are organized and conducted: Developing a monitoring system with data collection and construction of indicators starts with review of the program's detailed logic model. From the logic model, it is possible to identify key activities, expected program participants, expected outputs, and, perhaps, some expected outcomes that are conducive to monitoring, such as number of technologies under commercialization. A closer look at projects or research activities that comprise a program or initiative reveals the technical goals, against which progress can be tracked. After deciding what to monitor, the next step is to establish the supporting data collection strategies, databases, and information technology framework. It is necessary that program management identify which indicator metrics will best provide interim guidance. Often graphical depictions of the selected indicators are helpful in revealing trends in key program functions, and in guiding mid-course corrections. When evaluation studies are launched, the data collected through program monitoring tend to be invaluable. For example, records of publication and patent outputs are needed to support citation studies. Records of program participants are a starting point for network studies. Records of funded projects are a starting point for carrying out case studies. Records of commercial progress are helpful in organizing economic studies.

Limitations: The success of monitoring depends on appropriate selection of what is monitored. Moreover, interim indicators of progress are just that; they are not measures of ultimate, achieved outcomes and impacts. A further complicating factor is that a program often has multiple goals and it may be difficult to know how multiple indicators inform the multiple goals.

Uses:

- To track interim program progress.
- To guide mid-course corrections; provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.
- To support evaluation studies.

Example: Two examples are given. The first illustrates DOE and EERE performance monitoring systems that serve as reporting and analysis tools to support EERE R&D planning and management. The second illustrates a monitoring system used by the National Institutes of Health (NIH) called the Program Performance Monitoring System (PPMS).

<u>Example 1: EERE CPS, DOE Joule and EERE EIS performance monitoring systems</u>
DOE and EERE have the performance monitoring systems that cover parts of the program performance spectrum – The EERE Corporate Planning System (CPS), the DOE Joule Performance Measurement Tracking **S**ystem, and the EERE Executive Information System (EIS).

The ***CPS*** is a reporting system that collects and tracks information about milestone achievements as well as financial performance (e.g., cost and obligation data). This information is collected and reported at the project and contracts levels. The CPS provides quarterly detailed tracking of achievement of project level goals, which are primarily output measures of research/technology development accomplishments.

Joule is the name of a program performance tracking system that DOE uses to track and validate programs' performance measures. Joule tracks progress toward program goals and important accomplishments that are stated as official program R&D targets in the reports to Congress and the OMB. Joule performance measures for R&D (and non-R&D activities, as well) are incorporated in the annual Congressional budget justifications because doing so encourages budget and performance integration (required by the Presidential Management Initiative, PMI).

Joule performance measures tend to be annual output measures and sometimes include interim outcomes. The measures are defined at the project or project portfolio levels. Table 2-1 provides an example of annual Joule performance targets reported at the project portfolio level for Photovoltaic R&D in the EERE Solar Energy Program.

Table 2-1. Joule Performance Measures for Solar Photovoltaic Energy Systems Research

FY 2002 Results	FY 2003 Results	FY 2004 Results
Photovoltaic Energy Systems		
Reduce the manufacturing cost of PV modules to $2.25 per Watt (equivalent to a range of $0.20 to $0.25 per kWh price of electricity for an installed solar system). [MET]	Reduce manufacturing cost of PV modules to $2.10 per Watt (equivalent to a range of $0.19 to $0.24 per kWh price of electricity for an installed solar system). [MET]	Verify, with standard laboratory measurements, U.S.-made commercial production crystalline silicon PV modules with 12.5 percent conversion efficiency.
		Verify, with standard laboratory measurements, U.S.-made commercial production thin-film PV modules with 10 percent conversion efficiency. [MET]

FY 2005 Results	FY 2006 Targets	FY 2007 Targets
Photovoltaic Energy Systems		
Verify, using standard laboratory measurements, a conversion efficiency of 13.5 percent of U.S.-made, commercial crystalline silicon PV modules. Production cost of such modules is expected to be $1.95 per Watt. [MET]	Verify, using standard laboratory measurements, a conversion efficiency of 13.8 percent of U.S.-made, commercial crystalline silicon PV modules. Production cost of such modules is expected to be $1.90 per Watt.	Verify, using standard laboratory measurements, a conversion efficiency of 14.5 percent of U.S.-made, commercial crystalline silicon PV modules. Production cost of such modules is expected to be $1.80 per Watt.
Develop thin-film PV modules with an 11.0-percent conversion efficiency that are capable of commercial production in the U.S. [MET]	Develop thin-film PV modules with an 11.2-percent conversion efficiency that are capable of commercial production in the U.S.	Develop thin-film PV modules with an 11.8-percent conversion efficiency that are capable of commercial production in the U.S.

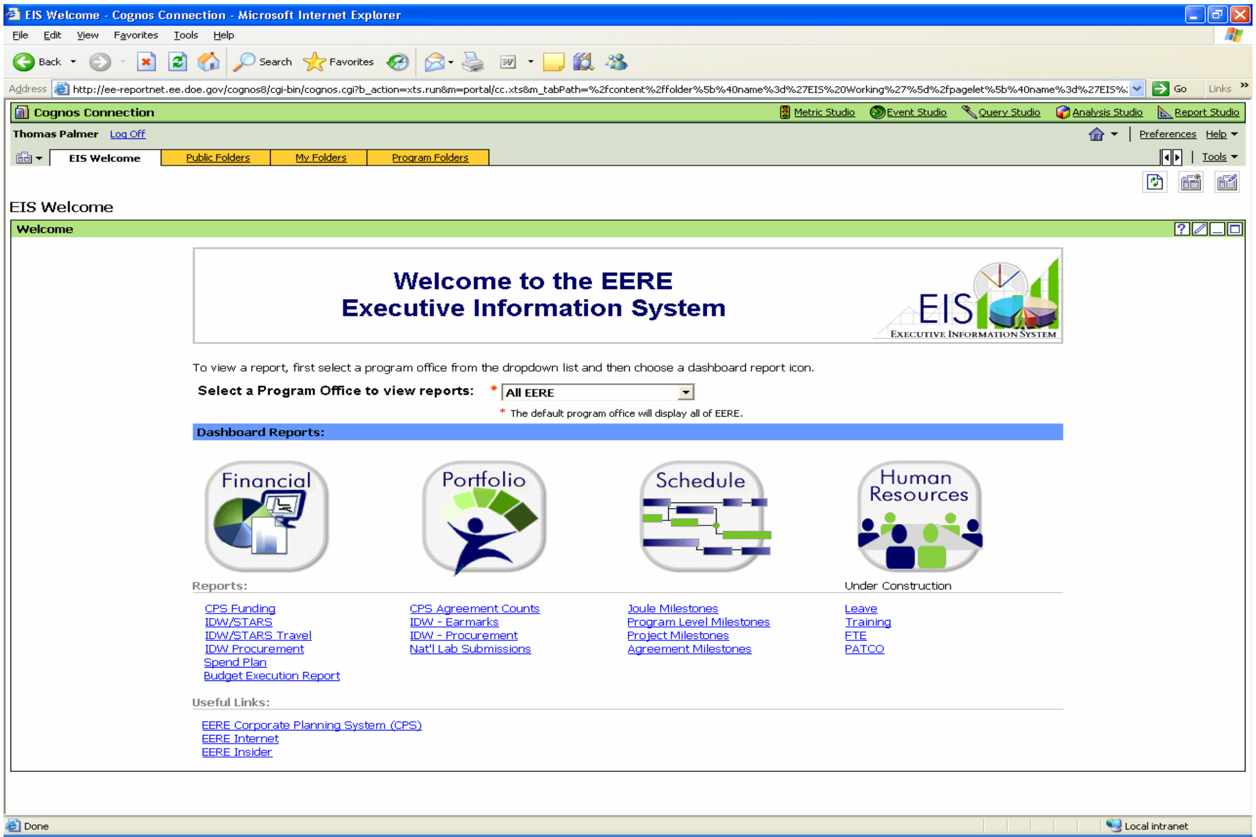
Each DOE program submits quarterly and annual Joule targets into a centralized database. Progress toward their target achievement is monitored throughout the fiscal year by an independent DOE Office.

Joule includes an external auditing mechanism. A set of randomly-selected program targets are chosen by DOE for auditing which may include, for example, the review of completed technical reports to verify that a stated target has been met according to defined criteria. Joule also provides color ratings *(green, yellow, and red)* to give a quick look display of its overall assessment results – green (100 percent of a target or goal is met), yellow (80-99 percent is met) and red (unmet if (<80 percent is met), Programs' progress against its Joule performance measures is publicly reported in the annual DOE Performance and Accountability Report.

The ***EIS*** is a performance reporting and analysis tool. It is a central repository that provides integrated project and program level information to EERE Senior Management and program staff. The EIS integrates many separate databases containing performance information. It aligns key financial, portfolio, schedule and other information. Its design enables it to have analysis capability for use in creating quick and ready performance reports and for analysis of performance trends (at program level or across the entire EERE portfolio). Figure 2-1 shows a screen shot of the EIS Dashboard – the portal to entry to the EIS system.

The CPS, Joule and EIS monitoring systems contain data exchange and transfer functionality. Together they serve as a useful 'early-warning' device for assessing performance of R&D and other activities in DOE. DOE and EERE are making further enhancements to these performance monitoring systems at this time.

Figure 2-1. Screen Shot of EIS Dashboard



Source: EERE's Executive Information System, presentation by Thomas Palmer Jr. (DOE, 2006)

Example 2: NIH's Program Performance Monitoring System (PPMS)

The example given here is of an advanced, state-of-the-art centralized program performance monitoring system developed for use by the National Institutes of Health, called the Program Performance Monitoring System (PPMS). [11] The example demonstrates that Information Technology (IT) tools are foundational to the management of information and of programs.

The example PPMS achieves both the connection of information contributors and the collection of the information within an organizational knowledge infrastructure. The system consolidates information, makes it readily available to users throughout the organization, and provides tools for organizing and displaying the data needed for management support and to meet ongoing internal and external reporting requirements. Although other programs have developed program monitoring systems, none have the IT sophistication of the illustrative system. However, the system is limited in that it collects performance data only for a relatively small number (70) of representative projects.

[11] This description of NIH's centralized performance monitoring system is based on a paper and presentation by Duran, 2006.

The focus of the NIH information system is data from its extensive and complex biomedical research portfolio arising from 27 institutes and centers. To be responsive to new medical information, emerging scientific opportunities, and public health needs, it is critical that NIH management have a monitoring system of its research programs. For annual planning and budgeting, management needs timely information on performance goals, progress, and budgets across the entire organization. To comply with government reporting requirements, NIH needs a systematic approach for collecting performance and budget information across these institutes and centers. The new IT-driven monitoring and repository system is far more efficient than the old system which required extensive manual activities, meetings, and working groups over considerable time to gather and consolidate paper-based information—which immediately became dated. The new system with its emphasis on visual support is also more effective in delivering information in formats that enhance user understanding.

The website for the PPMS, http://nihperformance.nih.gov, comprises two Web-based serves. One enables public access to publicly released performance monitoring information, reports and news. The other is secured for authorized NIH user-participants. The designation of user classes supports general public inquiries, researcher needs, in-house data entry and report generation, and senior management access to reports and supporting graphics and the capability to generate analytic reports.

Built into the application software is a project performance monitoring questionnaire that facilitates display of performance information for each project. System filters allow users to look at selected area of consolidated data, and to view progress against targets. A performance scoring tool in the system provides, for example, comparisons of actual performance to the target for Key Performance Indicators (KPI). This tool enables navigation through the system to assess progress in different areas and highlights those areas needing improvement. The system can be used to assess performance against core criteria—in the case of NIH, scientific risk (low/medium/high), time horizon (short-, mid-, and long-term), intramural versus extramural science, annual targets and budgets, and other criteria. Figure 2-2 shows a screen from the monitoring system showing the number of goals classified as basic or clinical or both, and classified by risk level.

It is important to note that the results of evaluation studies are not generated by the PPMS, but results from evaluation studies can be entered into the information system. The data in the system are used to produce analytical reports for performance monitoring and analysis. At the click of a button, the system generates performance reports for GPRA, PART, scorecard, and other required reports based on the stored data, reportedly saving many staff hours in report preparation.[12]

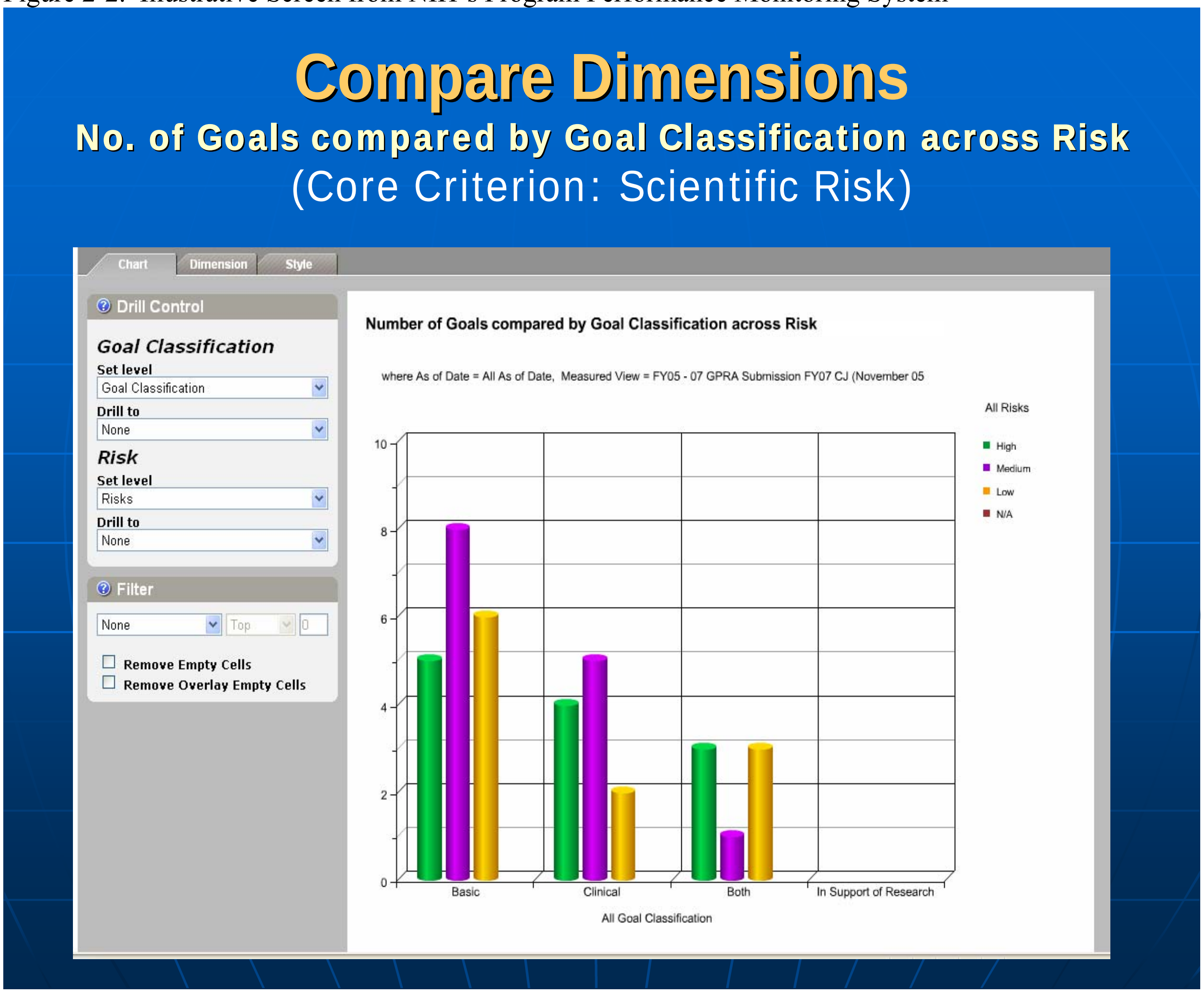
With input from NIH's Systemic Assessment Branch, an email alert notification system automatically and routinely alerts users to due dates, incomplete submissions, late submissions, items requiring approval or verification, and needs for revisions. Further, when the emails are referencing a particular place in the system that needs attention, the email is hyperlinked to the referenced page in the system.

Program officers are able to analyze data within the system in a variety of ways and from different perspectives. They can drill down to greater detail, identifying specific problem areas as well as

[12] The budget module of the system is under development and slated for deployment later in 2006.

areas of potential opportunity. They are able to see trends and comparisons of trends. They have available to them a variety of options for changing and customizing graphical displays. A user satisfaction survey is built into the system, and updates to the software are regularly conducted to respond to user inputs and recommendations for improvements. An online evaluation tool is also used to identify the frequency with which content is accessed, the type of activities performed most often, and other dimensions of the effectiveness of user experiences with the system.

Figure 2-2. Illustrative Screen from NIH's Program Performance Monitoring System



Source: Duran, 2006.

In summary, the NIH has established a state-of-the-art online performance monitoring system that enables recording and tracking science content, science advances, and research progress against prospective annual targets, and provides a centralized resource for performance information for planning, analyzing, and reporting on performance. According to NIH staff that oversees the system, it is highly successful. A note of caution is offered, however: critical to success is the close alignment of knowledge management with the organization's specific needs for performance monitoring.

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Thomas Palmer Jr., "EERE Executive Information System," presentation at Cognos 4th Annual Government Forum, May 2006

2.3 Bibliometric Methods – Counts and Citation Analysis

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. Design/revise, plan, select, budget
2. **Make R&D progress, review processes, achieve outputs**
3. **Disseminate outputs, achieve interim outcomes**
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- Planning information
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- **Creation and dissemination of knowledge outputs**
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- Spillover effects
- Comparative standing
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

Bibliometric methods are used to show that knowledge has been created and disseminated, and to show emergence of new ideas and development of relationships and patterns. These methods use text and text-related materials to evaluate R&D programs [13] They are particularly relevant to R&D evaluation because the output of research typically is knowledge, and knowledge is often expressed at least in part in reports, publications, and patents. Bibliometric methods include counting publication and patent outputs, analysis of citations of publication and patent outputs, and data mining of textual materials. The focus of this section is on counts and citation analysis which are used to show knowledge creation and dissemination, and to identify users of a program's knowledge.

Definition: Counts of publications and patents are often used by R&D programs as indicators of program knowledge outputs. Citation analysis of publications and patents is used to reveal relationships and linkages between a program's knowledge outputs and efforts undertaken by others. Citations demonstrate the dissemination of knowledge, creating conditions for knowledge spillover benefits. The frequency of citations may signal the importance of a program's

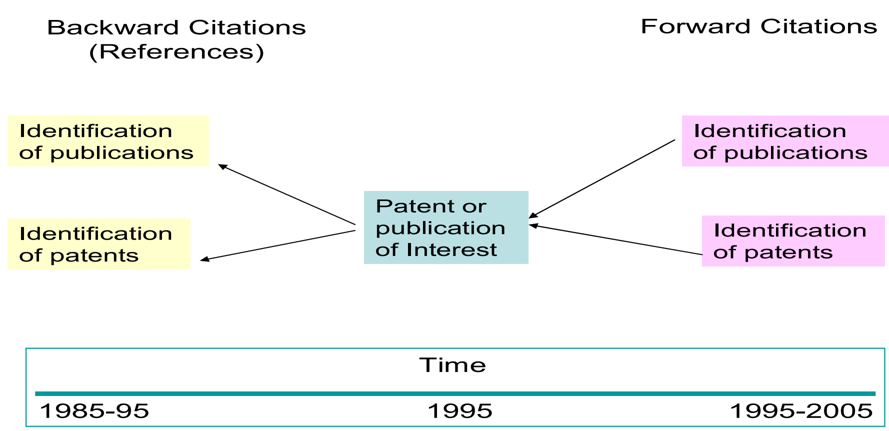
[13] A recent extension of bibliometrics, called "webmetrics" or "cybermetrics" widens the scope to analysis of relationships among different web sites, identifying those that are most useful or influential based on the frequency of hyperlinking to other web sites. This extension could become relevant to evaluation of Federal R&D programs if programs increasingly use web sites to disseminate non-published program outputs.

knowledge outputs to others. Counts of publications and patents filed are often included among an R&D program's outputs, and measures of patents granted and citations of publication and patents are often used in assessing an R&D program's outcomes. Evaluators are increasingly using patents and their citations as indicators of innovation, information flow, and value creation.[14]

How biliometric studies of publication and patent counts and citations are organized, conducted, and analyzed: Tabulating counts of publications and patents is relatively straightforward. These records are often routinely compiled by R&D organizations in their publication review and approval and patent filing processes and captured in program performance monitoring systems. Search engines may also be helpful in compiling data on publications and in making comparisons.[15] Citations analysis is generally performed as a forward search in time from an initial publication or patent program output to downstream publications or patents which cite that produced by the program, but it may also be performed backward to attribute current work to knowledge generated in the past by your program or organization.

Figure 2-3 illustrates looking both forward and backward in time for citations of either publications or patents. In the center is the publication or patent of interest.

Figure 2-3. Diagram Showing Forward and Backward Citations of Publications and Papers



[14] In addition to using citation analysis for program evaluation, researchers have investigated citation-based patent measures to develop financial market valuation of firms owning the patents, and at least one company is now using citation-based valuation to provide stock investment services. (See, as an example of the research on this topic, Hall, Jaffe, and Trajtenberg, 2001; and see, as an example of an investment service based on this method, ipIQ, formerly CHI Research.).

[15] Among the multiple search engines is Thomson Scientific's "Web of Science" (WOS), an electronic search engine for accessing more than 8,500 research journals, and "Web of Knowledge," an electronic search engine for accessing multiple citation indices (including Science Citation Index, Social Sciences Citation Index, and Arts & Humanities Citation Index, and over 100 years of backfiles). These may be accessed by annual subscription or on a pay-as-you-go basis, and the company also offers to build "custom information solutions" for a fee. Many institutions have existing access to these services, and more information about them can be found at http://scientific.thomson.com.

Performing citation analysis requires compilation of sufficient details of individual publications and patents—not just counts—to provide accuracy and completeness of records needed to permit searches. Attention typically is needed to ensure proper matching in database searches, e.g., to determine if J. E. Smith is the same as Joe Smith.

After the pool of program-related publications or patents is identified, computerized tools can be used to track subsequent publications or patents that refer as prior art to each of those that derive from the program, and the links can be recorded. This process is repeated in turn for each of the publications or patents that cite the originals until the chain of references is complete. The results can be displayed in graphic format.

For patent citation analysis, the U.S. Patent Office now makes it possible for anyone to search patent data on-line. And there are also special databases and search services which can facilitate patent citation searches.[16]

Patent Weasel: The Patent Weasel, developed by Pacific Northwest National Laboratory (PNNL), is a data system for ferreting out trends and relationships in the DOE's patent portfolio. The system contains over 11,000 DOE patents and over 41,000 citing patents, reflecting over 61,000 citations. The Weasel allows users to identify, locate, and retrieve potentially interesting technologies that have been developed and patented through DOE funded R&D efforts. Patent Weasel Beta V1.2 can be ordered.[17] The examples section includes an example using this tool.

Limitations: There are several limitations of the method of counting and citation analysis. Issues arise in terms of what to count. Quality issues arise in using counts of publications and patents as output indicators, or counts of citations as an outcome indicator, because simple counts do not distinguish differences in quality and in purpose. In publication analysis, weighting schemes have been used to control for quality differences among journals in which publications and citations appear. Citations counts have also been improved by adjusting for self-citing and for the practice of citing work for which there is no real intellectual link. However, calibrating for quality differences among scientific works remains imperfect, often inadequate, and time consuming. Furthermore, problems with incomplete references and lack of attribution to program funding may frustrate, limit, and bias counts and citation analysis and/or require data cleaning and additional research before proceeding. A further limitation in comparing publishing and patenting rates across different fields, specialties, and institutions is that publication and citing policies and practices may vary by intention. Organization or country size, of course, influences publication and patent outputs, and, hence, comparisons across organizations or countries of different size

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[16] For example, the National Bureau of Economic Research (NBER) provides detail information on about 3 million U.S. patents granted from 1963-1999, all citations made to these patents from 1975-1999, and a broad cross-match to firm data in Compustat, free for use by researchers (see www.nber.org/patents/. Thomson supports patent citation analysis using the Derwent World Patent Index, as a subscription service (see http://scientific.thomson.com/support/patents/swpiref/reftools/search). Previously CHI Research performed citation analysis for a number of government R&D programs; since it refocused its business, several of its researchers have formed a new company, 1790 Analytics LLC, which offers citation analysis in support of science program assessments (see www.1790analytics.com).

[17] Patent Weasel Beta V1.2 can be ordered using information at the WREN website, http://www.wren-network.net/resources.htm.

require some form of standardizing, such as papers or patents per dollar of research budget. Despite efforts to standardize, cross-discipline comparisons of outputs remain problematic—for example, how does a paper in photonics compare with a paper in tissue engineering? Finally, while counts show publication or patenting activity and an analysis of citations suggest the popularity, and, by implication, the relative importance of underlying R&D to others, neither provide an explicit measure of value to downstream users.

Uses:

- To provide measures of program knowledge outputs and evidence of outcome in the form of knowledge dissemination and knowledge spillovers.
- To reveal linkages from Federal R&D to downstream outcomes.
- To identify users of a program's knowledge and technology, defined as those who cite its papers and patents—a critical step in attempting to quantify the value of knowledge spillovers.

Examples: Four examples are provided. The first example illustrates the use of counts of patents to compare the patent outputs over time of three R&D organizations, and it also shows annual publication output for one of the organizations against its targeted output level. The second example shows the use of DOE's Patent Weasel to gain insight into the breadth of intellectual property development in various technical areas funded by DOE and EERE. The third example illustrates the use of two forms of "patent trees" to identify use of a project's knowledge outputs by others. The fourth example shows how publication citation analysis can reveal the influence of Federal research on downstream, private-sector innovation.

<u>Example 1: Using counts of publications and patents as outputs and performance indicators</u>
The Department of Commerce (DOC) issues an Annual Report on Technology Transfer for the National Institute of Standards and Technology (NIST), the National Oceanic and Atmospheric Administration (NOAA), and National Telecommunications and Information Administration (NTIA) that includes tables spanning several years with counts of multiple program outputs, including patents from its three Scientific and Technical units (Table 2-3), and a table spanning the same period with counts of technical publications produced by NIST (Table 2-4). These program outputs are routinely compiled and made publicly available by DOC to show technology transfer by these components of the agency.

Table 2-3. Counts of Patent Granted for NIST, NOAA, and NTIA, FY 1999-2001

	1999	2000	2001
Patents Issued in the FY for Laboratory Inventions, total	28	16	22
NIST	26	14	20
NOAA	2	2	1
NTIA	0	0	1

Source: DoC Annual Report on Technology Transfer, FY 2001, June 3, 2002.

Table 2-4. NIST Publication Outputs, FY 1999-2001

	1999	2000	2001	
Technical publications produced	2,270	2,250	2,207	Annual number of technical publications generated by NIST's technical staff. The number is a direct count of the number of technical publications cleared for publication by the NIST Editorial Review Boards at the Gaithersburg and Boulder sites. Over time, NIST expects a relatively constant level of high quality publications (2,000-2,200 per year) produced by its technical staff. Of the publications produced annually, approx. 80% are approved for external publication (such as in scientific journals); the other 20% are NIST reports and special publications.

Source: DoC Annual Report on Technology Transfer, FY 2001, June 3, 2002.

<u>Example 2: Using the Patent Weasel to identify patents and compare patent outputs resulting from DOE-funded research with other patent output data</u>

The analysis of patents showed that if DOE had retained the rights to all the patents issued to its laboratories and contractors between 1976 and 2003, it would rank fourth in comparison with American companies, ranking behind only IBM, GE, and Eastman Kodak.[18] Table 2-5 summarizes the DOE patent data uncovered by the Patent Weasel analysis.

Table 2-5. A Summary of DOE Patent Data Uncovered by the Patent Weasel

DOE Patent and Citation Breakout

Parameter	EERE*	SC	FE	Other	Total
Total Patents	651	4,982	749	7,643	14,025
Percent of DOE Patents	4.6%	35.5%	5.3%	54.5%	100%
Total Citations	4,168	33,847	4,219	51,527	93,761
Percent of Total DOE Citations	4.4%	36.1%	4.5%	55.0%	100%
Average Cites per Patent	6.4	6.8	5.6	6.6	6.7
Avg Yrs to First Citation for Cited Patents	2.9	3.5	2.9	3	3.4
Total Non-DOE Citations	3,690	29,203	3,461	46,251	82,605
Average Non-DOE Cites per Patent	5.7	5.9	4.6	6.1	5.9

*EERE Patents were defined as originating from work conducted at NREL or containing "EE" or "CE" in the reference contract.

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Source: Eike, 2005.

[18] This example of data generated by the Patent Weasel and conclusions drawn are based on a presentation by David Eike, PNNL, 2005.

Table 2-6 shows the EERE patents by technology classification as a percentage of all DOE patents, and indicates those areas in which EERE patents are a greater percentage than predicted. Figure 2-4 shows all citations of DOE patents by technology area.

Table 2-6. A Summary of EERE Patents by Technology Area and as a Percent of All DOE Patents

EERE Patents by Class as Percent of All DOE Patents

USPTO Classification	All DOE	EERE	EERE %
Semiconductors	202	44	22%
Crystals	98	13	13%
Fluid handling	153	19	12%
Electricity and electrical devices	1118	128	11%
Coating processes/apparatus	310	31	10%
Active solid-state devices	98	9	9%
Engines, motors & pumps	413	28	7%
Power plants	169	10	6%
Chemistry	2738	155	6%
Heating & heat exchange	509	28	6%
Optics & optical systems	708	26	4%
Materials	1084	38	4%
Other	1760	57	3%
Computers & data processing	385	11	3%
Liquid purification or separation	235	6	3%
Refrigeration	164	4	2%
Metal working	608	14	2%
Gas separation	159	2	1%
Wells	86	1	1%
Radiant energy	696	8	1%
Measuring and testing	562	6	1%
Communications	218	2	1%

EERE % greater than predicted

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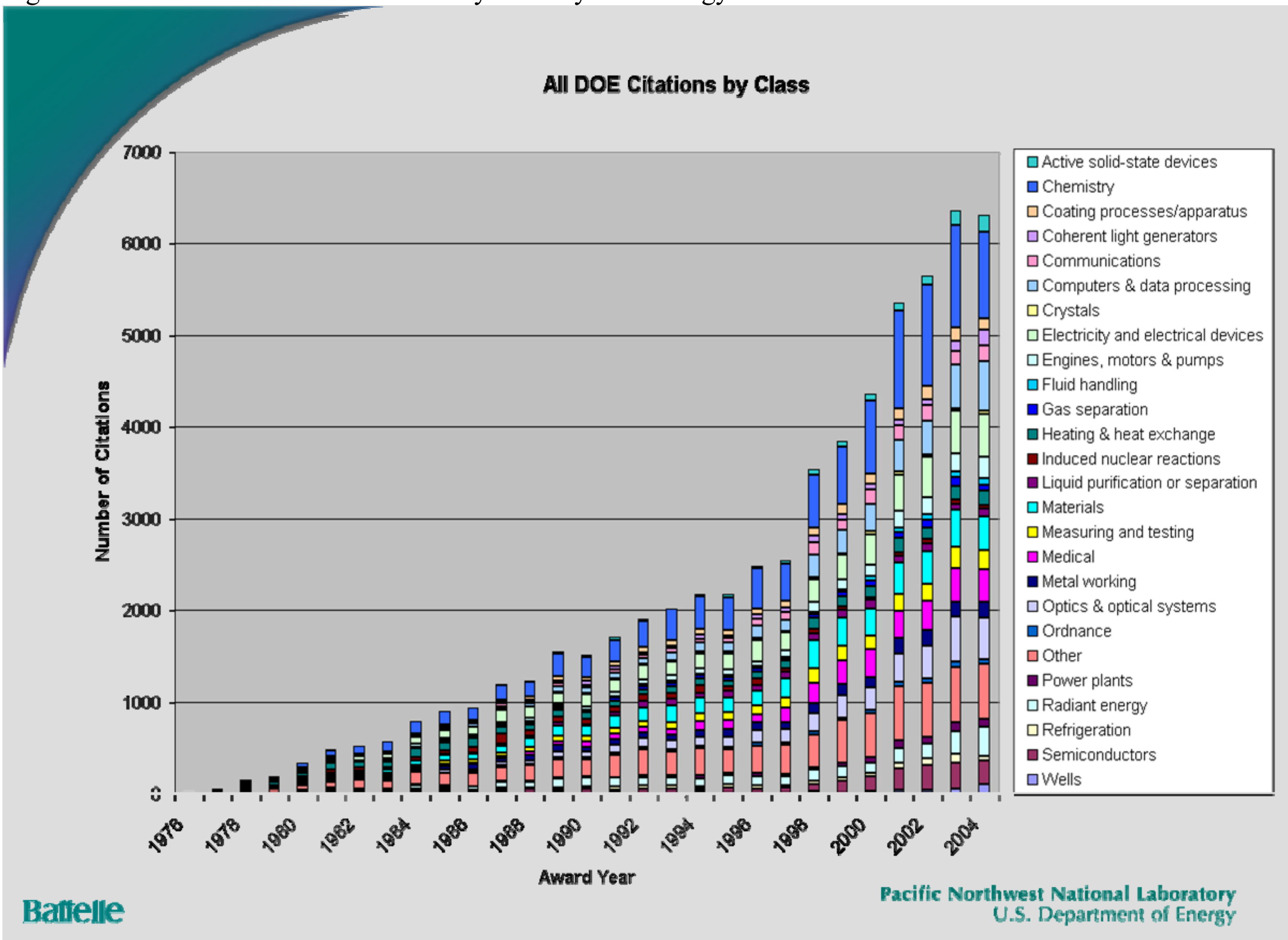
Pacific Northwest National Laboratory
U.S. Department of Energy 14

Source: Eike, 2005.

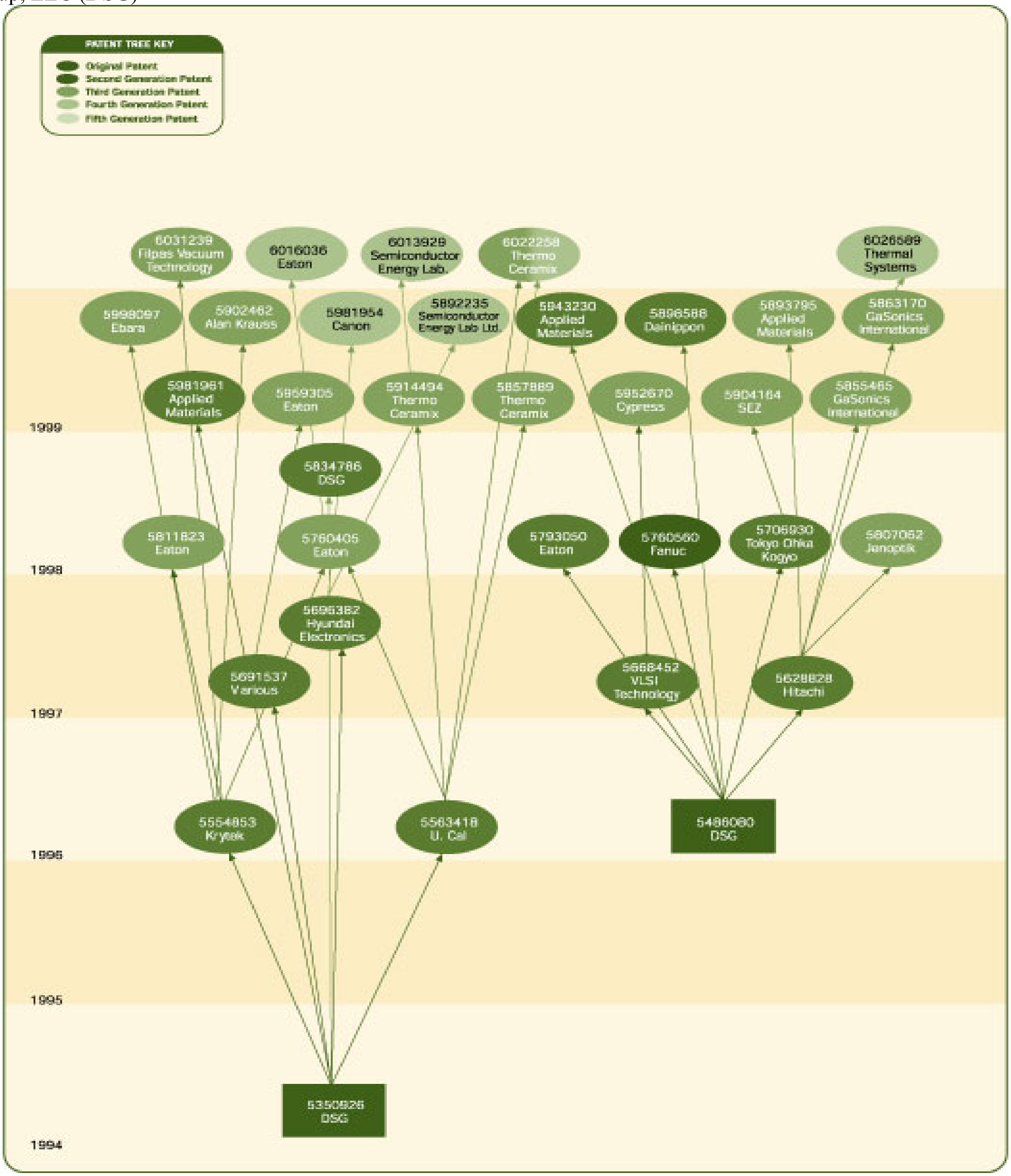
Figure 2-4. Citations of Patents Funded by DOE by Technology Area



Source: Eike, 2005.

<u>Example 3: Using project patent trees to show use of a project's knowledge outputs by others</u>
"Patent tree" diagrams can be used to show forward citations of patents from a program's research. Figure 2-5 shows two patents attributed to funding by the Advanced Technology Program (ATP) of a single project carried out by Diamond Semiconductor Group (DSG). The two boxes in the lower part of the illustration represent the patents granted to DSG and attributed to ATP funding. The "balloons" linked to these boxes show subsequent patents (and the organizations holding the patents) that cited the patents from the ATP-funded project. The lighter the shade of balloon, the further removed is the citing patent from the original patent, moving from dark (first generation) to lightest (fifth generation). With the passage of additional time, there are likely new branches that have emerged as outgrowths of the earlier patents. To the extent that the later occurring patents are dependent on the earlier ones, the patents in the patent tree represent developments in knowledge that would likely not have occurred in the same timeframe, had the ATP not stimulated the creation and dissemination of the underlying knowledge platform.

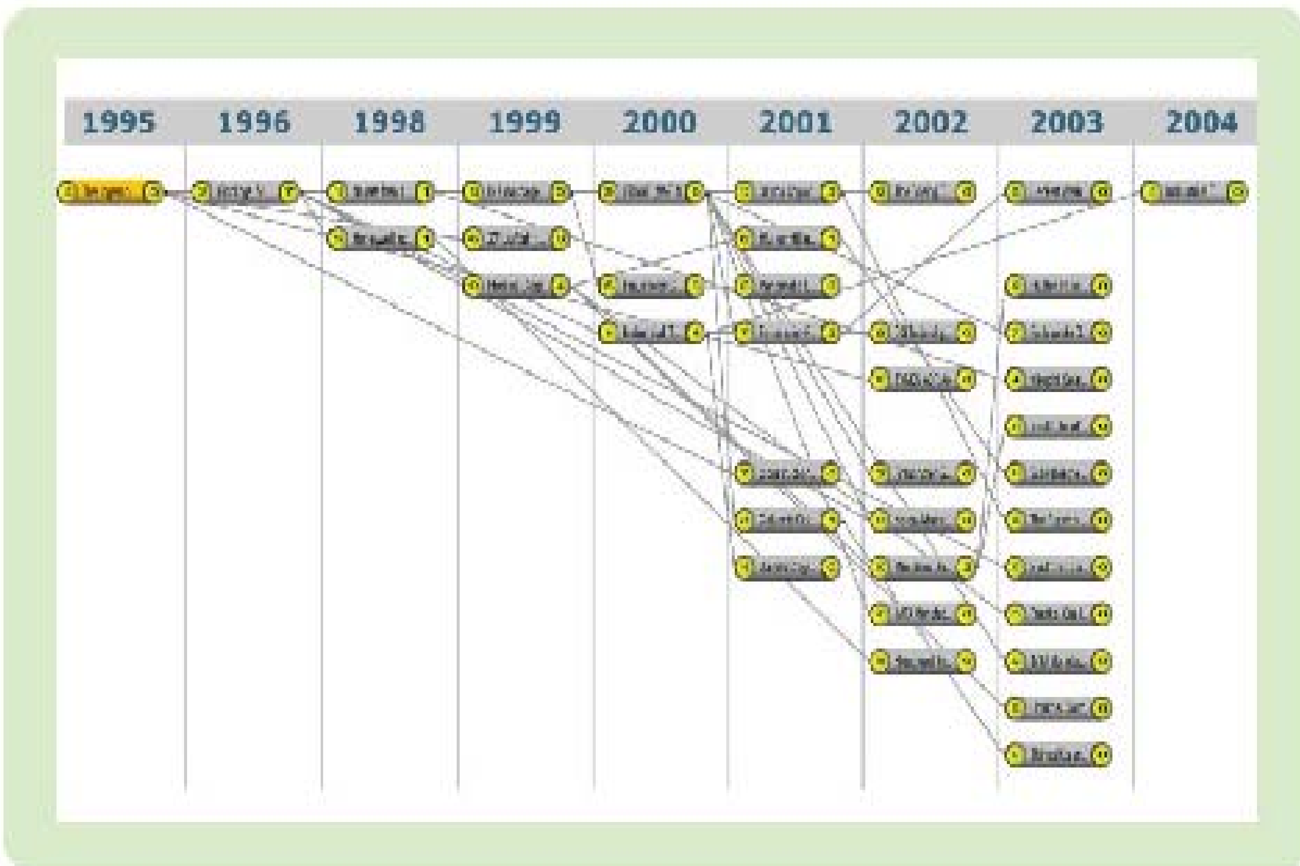
Figure 2-5. Illustrative Patent Tree for an ATP-funded Project Carried out by the Diamond Semiconductor Group, LLC (DSG)



Source: ATP, *Performance of 50 Completed ATP Projects*, Status Report-Number 2, December 2001, Diamond Semiconductor Group, LLC (DSG).

Figure 2-6 illustrates the use of a different graphical portrayal of the pattern of post-project patent citations for an ATP-funded project conducted by Ingersoll Milling Company. In contrast to the previous case, in this case the company went bankrupt, truncating the direct path to commercial benefits. Nevertheless, this graph shows that the project generated knowledge in the form of a single project-derived patent that was cited over the following years by multiple organizations. Hence, the project's long-run benefits in the form of knowledge spillovers may make the project worthwhile even though the funded company went under, but the patent citation analysis alone is merely suggestive of this and not conclusive.

Figure 2-6. Patent Tree for Ingersoll Milling Company – Patent 5,392,663 – Showing "Indirect" Project Impact though the ATP-funded Innovator Went Bankrupt



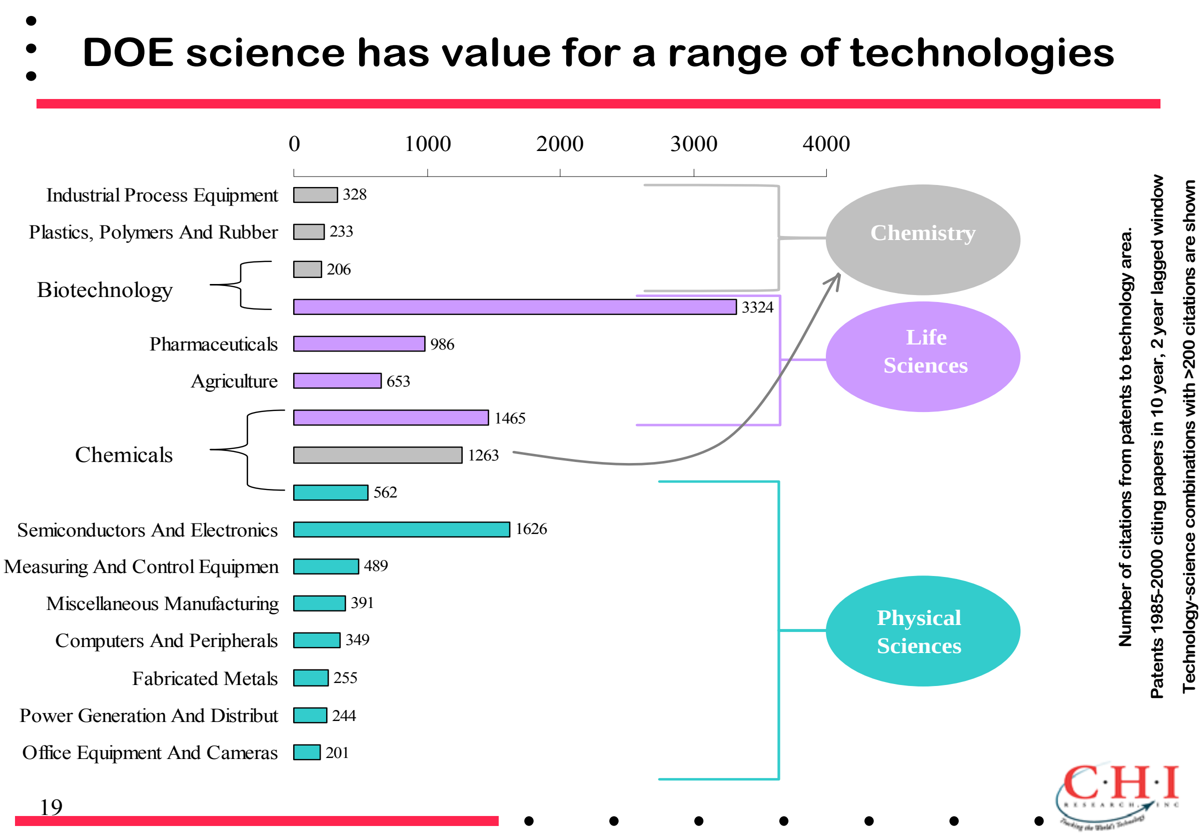
Source: ATP, Performance of 50 Completed ATP Projects, Status Report Number 3, 2006, p. 11, Ingersoll Million Company.

Patent trees can be valuable for showing knowledge spillovers from a program's funded projects. ATP, for example, used patent trees to demonstrate progress along an "indirect path" of program impact–i.e., via knowledge flows–in supplement to benefits realized by the program through its "direct path," i.e., through commercialization of technologies developed by direct program participants and their partners.

<u>Example 4: Using publication citation analysis to show broad influence of Federal research on downstream, private-sector innovation</u>
An early study sponsored by NSF and conducted by CHI Research, Inc. (now ipIQ) used citation analysis (enhanced by tracing institutional ties of authors) to provide strong evidence that "publicly financed scientific research plays a surprisingly important role in the breakthroughs of industrial innovation in the United States…"[19] The study found that 73% of the main science papers cited by U.S. industrial patents in a two-year period were based on domestic and foreign research financed by government or nonprofit agencies. The study called publicly financed science the "fundamental pillar" of industrial advance, and "strongly suggested that publicly funded science lies at the heart of most commercial innovation."[20]

DOE has furthered the art of citation analysis and sponsored its use to study the impact of DOE science on emergent S&T areas. For example, as illustrated in Figure 2-7, DOE has used citation analysis to show that DOE science is cited by others in a variety of S&T areas.

Figure 2-7. Illustration of patents citing DOE publications and patents in multiple emergent technical areas, 1985-2000



Source: Diana Hicks, Indicators of Knowledge Value, Conference on Estimating the Benefits of Government Sponsored Energy R&D, March 2002.

[19] William J. Broad, "Study Finds Public Science is Pillar of Industry," *New York Times*, May 13, 1997, Science Desk, quoting from a study sponsored by NSF and conducted by CHI Research, Inc. (now ipIQ).
[20] Ibid.

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U.S. Department of Energy, Pacific Northwest National Laboratory (operated by Battelle Memorial Institute), Patent Weasel description.

2.4 Bibliometric Methods – Data Mining

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. **Make R&D progress, review processes, achieve outputs**
3. **Disseminate outputs, achieve interim outcomes**
4. Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts

Information Provided by Evaluation Methods:

- **Planning information**
- **Indicators of interim progress**
- **Analysis of collaborative and other relationships**
- **Creation and dissemination of knowledge outputs**
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- Spillover effects
- Comparative standing
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

Data mining is a bibliometric method which searches texts for keywords to identify the origin of important ideas and concepts. It is also used in evaluation to identify the emergence of relationships among research organizations and disciplines.

Definition: Data mining is the extraction of key concepts or relationships from large quantities of digitized natural language text. The method has also been called "literature-based discovery" (LBD), a descriptive name. As in the case of the other bibliometric methods, this approach focuses on written documents--a major output of research, and may include reports, publications, and textual components of patents or other documents. Data mining enables the efficient and effective management and use of large volumes of R&D texts by making it possible to integrate across document collections and to discover new information from existing sources.

How data mining studies are organized, conducted, and analyzed:
Data mining studies are organized to automate searches of large volumes of information in order to identify relationships and patterns of interest that would be slow, and difficult or impossible to find by human analysts working without specialized tools. Conducting a data mining study starts with the availability of subject texts in digital form; proceeds with computer processing using various search and analysis algorithms to extract useful information, and finishes with human analysis and interpretation of the results. Databases of technical reports, such as a program's database of its own reports and the many others that now exist (including, for example, Science

Citation Index, Engineering Compendex, Medline, NTIS Technical Reports, and RAND's RaDiUS database) can provide sources of text. Specialized data mining tools, developed and supplied by a variety of vendors, facilitate the processing step; examples include WORDSTAT a data mining module for SIMSTAT, SPSS tools for data mining, SAS data mining tools, among others. Information visualization support, such as that provided by PNNL, added to data mining serves as a valuable assist in gaining insight from the results.

Limitations: Data mining has its primary applications in commerce, e.g., to identify what products are likely of interest to a given customer, and how to promote them; in homeland security and national defense, e.g., to uncover patterns in communications of terrorists and military groups. The method has been less used by most Federal agencies for R&D evaluation--probably because of its emphasis on supporting future decisions rather than assessing the results of past investments. Yet, several agencies, including DOE, have used the method for evaluation and have developed supporting tools. An early barrier to using the method was the large resource requirement, but this has been overcome by highly efficient automated data mining systems, the availability of large amounts of computing power, and the digitization of text.

Uses:[21]

- To show the origin of important ideas and concepts; more specifically to show that past investments in an R&D program contributed to emergent fields and technologies.
- To show relationships among research organizations and disciplines.
- To influence public S&T policy by providing decision makers insight into how cutting-edge technologies develop from combinations of diverse research efforts over time.
- To gather technical intelligence that may alert evaluators to developments in precursor, rival, or complementary technologies affecting the impact of a technology of interest.
- To provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.
- To help guide investment decisions in R&D in emergent areas.

Examples: Three examples are presented. The first uses data mining and data visualization in combination to uncover relationships among research supported by the National Science Foundation (NSF) and by the National Institutes of Health (NIH). The second example combines data mining and data visualization to show how specific DOE publications and patents are linked to the emergence of nanotechnology as a technical field. The third example, from the Navy, shows the use of data mining to uncover technical intelligence that may be useful for evaluation.

<u>Example 1: Using data mining with data visualization to uncover research relationships</u>

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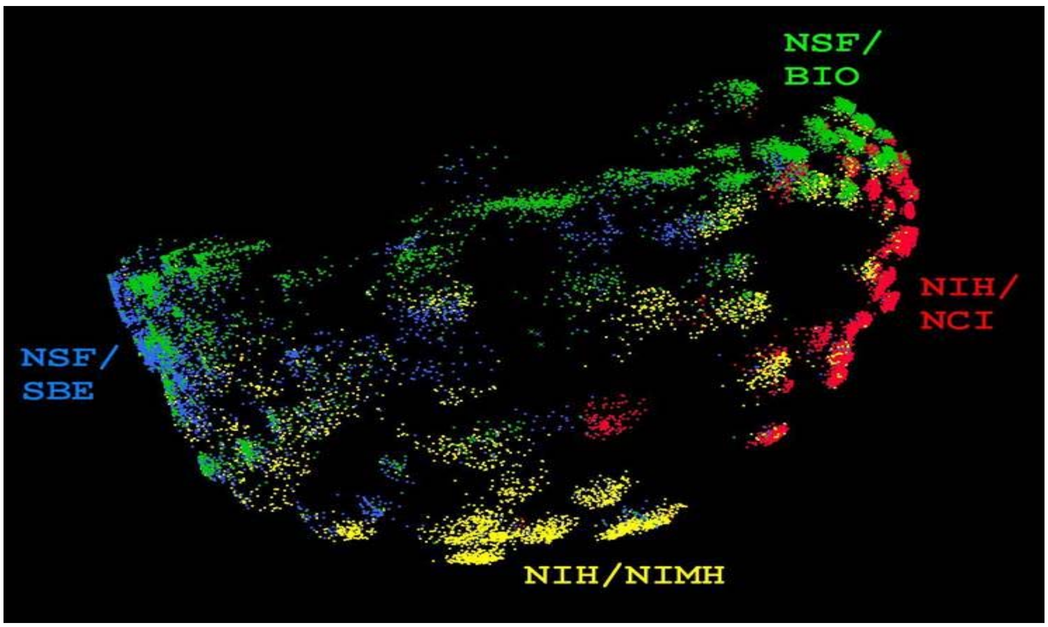
[21] The uses featured here are those that relate most directly to evaluation. Additional uses in S&T include extracting useful pieces of information from text that may lead to further discovery and innovation, and to uncover connections between seemingly unconnected disciplines and research fields in order to accelerate potentially radical discovery and innovation.

Figure 2-8 shows the coupling of data mining with data visualization to assess interagency and multidisciplinary S&T relationships at two NSF research units—Directorate for Biological Sciences (BIO) and Directorate for Social, Behavioral & Economic Sciences (SBE), and two NIH research units—National Cancer Institute and National Institute of Mental Health). PNNL's "Galaxies" software is used to accomplish the display.[22] Areas where the research comes together may be seen by adjacent color combinations. The software supports "visually going into the data" to take a closer look at areas of interest.

Figure 2-8. Data mining with Data Visualization Showing Relationships among Research Documents Produced by Two NSF Units and Two NIH Units



Source: Roberts et al, 2005

<u>Example 2: Using data mining with visualization to show emergence of a field, with DOE papers and patents superimposed to show specific DOE contributions</u>

Analysts at PNNL used data mining to analyze the emergence of the field of nanotechnology by uncovering the use of variants of the term "nano" in the open literature from 1988 forward.[23] As illustrated in Figure 2-9, they used data visualization software to depict this emergence as an ever-widening river over time as use of the term grew. Then, they superimposed specific DOE papers and patents over the flow, indicating their time of occurrence relative to the emergent field.

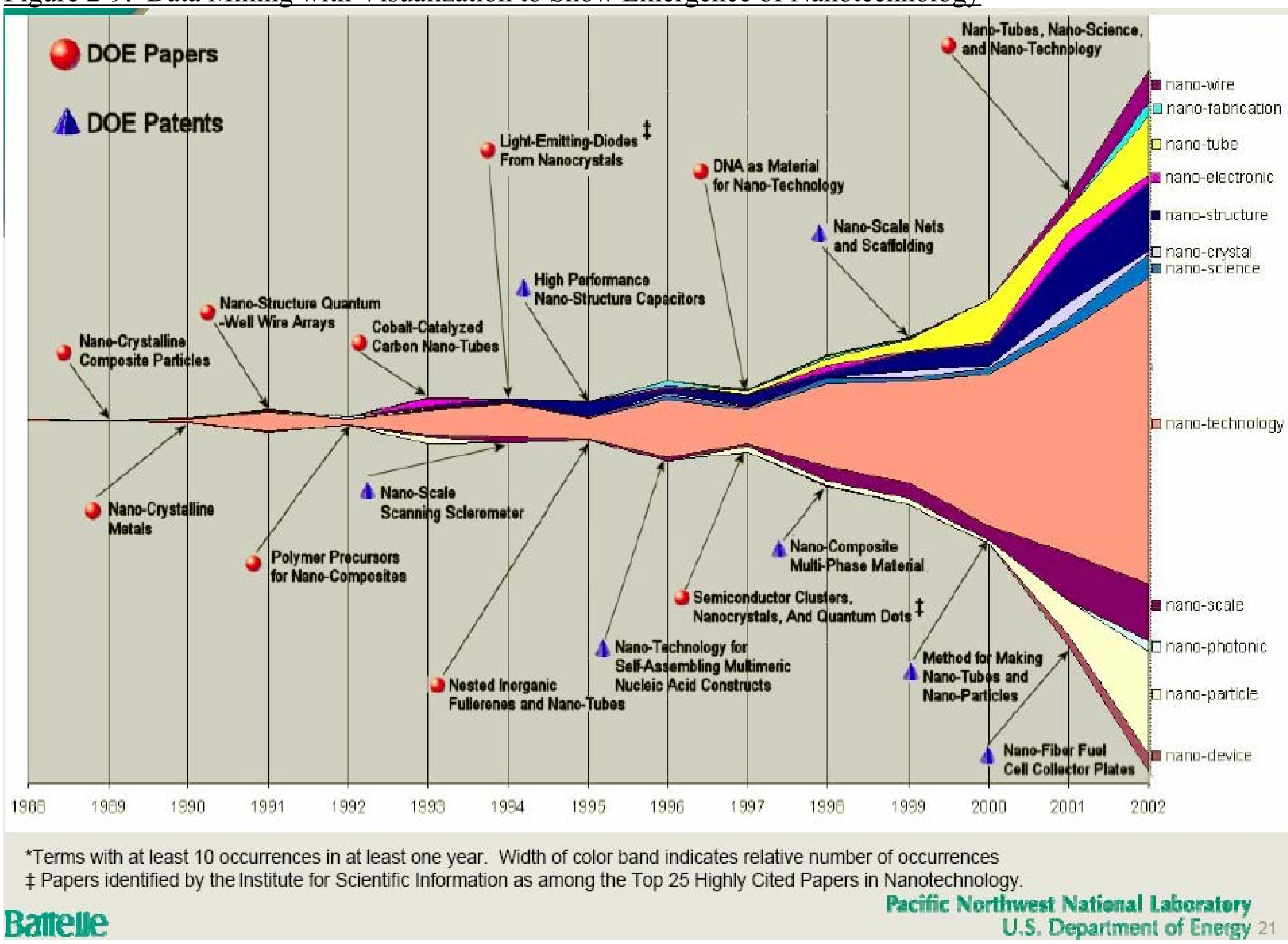
It should also be noted that among the DOE-contributed papers overlaid on the chart are several which have been identified by the Institute for Scientific Information as among the top 25 highly

[22] In addition to galaxy displays of information, topics or themes of interest within a set of documents can be displayed in other ways, such as a relief map of natural terrain or as a river that widens or narrows to depict changes in time-related patterns.

[23] Eike, 2004.

cited papers in the field of nanotechnology. This information reinforces the role of DOE research in development of the field.

Figure 2-9. Data Mining with Visualization to Show Emergence of Nanotechnology



Source: Eike, 2004.

Example 3: Using data mining to develop a larger picture and technical intelligence perspective of selected technical fields

As described by Kostoff, the Office of Naval Research (ONR) has used data mining to derive technical intelligence from the published literature on fullerence science and technology, including the theory, experimentation, computations, and applications related to large ordered carbon atom clusters.[24] Kostoff describes the use of the method also to obtain technical intelligence on aircraft S&T, power sources, and other applications of science and technology. He explains how the method has been used to identify what is state-of-the-art in a given technology area, identify the most active and prolific researchers and organizations in a technical area, identify closely related themes to a given technology, and develop program investment strategies.

Using textual mining to gain technical intelligence similarly could be helpful in evaluation to identify prerequisite, rival, and complementary technologies whose successful development and

[24] Kostoff (undated).

deployment might change the expected impact of technologies under development or planned by a U.S. R&D program.

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U.S. Department of Energy, Pacific Northwest National Laboratory (operated by Battelle Memorial Institute), Information Visualization, URL: www.pnl.gov/infoviz/index.html.
The visualization software is described and published papers are referenced and abstracted which provide additional information on combining data mining and visualization.

2.5 Bibliometrics -- Hotspot Patent Analysis

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. Design/revise, plan, select, budget
2. Make R&D progress, review processes, achieve outputs
3. **Disseminate outputs, achieve interim outcomes**
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- **Planning information**
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- **Creation and dissemination of knowledge outputs**
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- **Spillover effects**
- Comparative standing
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

A recently developed, specialized application of patent analysis in bibliometrics is "Hotspot Patent Analysis," which looks at patenting frequency to identify patents that appear to be having a particularly large impact on innovation and also "Next Generation Patents," which are building on "Hotspot Clusters." This analysis helps to assess the relative importance of a program's patents to technological innovation.

Definition: Hotspot patent analysis identifies patents that are highly cited by recently issued patents. The technique offers an unobtrusive and unbiased way to uncover technological "hotspot clusters," i.e., patented technologies that are currently having a large impact on innovation. According to recent studies, approximately 2% of recent patents are designated hotspots. Old patents can also be hotspots if there is a recent big spike in citations of them. (These are distinguishable from a "citation classic," a patent consistently cited over many years.)

Related are "next generation patents" which are the current patents citing the hot-spot patents. According to recent studies, approximately 24% of recent patents have been designated next generation patents. For a Federal R&D program, generating a high percentage of patents that are rated as "hot-spot patents" signals strong inventive activity by the program; conversely, spawning few high-spot patents may suggest that the program's inventions are offering incremental improvements or concepts with little perceived current value. Generating a high percentage of "next-generation patents" suggests that a program is funding applications that are building on hotspot clusters. The hot-spot and next-generation methodology arises out of bibliometric work with patents and offers new patent metrics.

How hot-spot patent studies are organized, conducted, and analyzed:
Hot-spot analysis is a specialty method developed by researchers formerly at Chi Research, Inc. The several studies that have been conducted for Federal R&D programs using the technique have been organized, conducted, and analyzed by researchers then with Chi Research.[25] The analysis requires preliminary patent data analysis and cleaning. The approach is suitable for assessing multiple technology areas and large programs, but can also be carried out for a given technology area or for a sub-group of related technologies. Such an analysis, for example, could be used to highlight important organizations and regions contributing to a field, and to identify those doing the high-impact research.

A hot-spot patent was defined in past studies as having at least 10 or more recent citations, and recent citations as a proportion of total citations was set proportional to the age of the cited patent. To be considered a hotspot patent, an old patent had to have at least 25% of its citations to be recent. The patents recently citing hot-spot patents—i.e., "the next generation patents"—are those building on the hotspot patents and are an important aspect of the analysis, because they may signal applications developing around generic technology platforms or widely applicable science concepts. Highly cited patents granted to businesses have been found to correlate well with inventor awards, increases in sales, profits, rise in stock prices, patent licensing, and successful products. Because it provides a means of identifying high-impact technology among companies and other organizations, the approach is relevant to competitive technical intelligence for businesses and governments. It is also relevant to public policy as a tool for identifying trends in innovation and for assessing an R&D program's contribution to emerging "hot" technology areas. Additionally, the analysis can show who is citing whom and where the companies with the hotspot patents and second-generation patents are located. Thus, the analysis can be useful in analyzing collaboration and regional influences, as well as assessing the appropriateness and effectiveness of the outreach activities of public programs.

Limitations: Whenever patent data are used, there tends to be issues with the completeness and accuracy of data records, requiring preliminary attention to data cleaning. In the case of hotspot analysis, experience with applying the method and interpreting the results is limited, the number of experienced practitioners is limited, and familiarity of stakeholders with the concept is also limited. Interpretation of results and their implications for different Federal R&D programs with their differing objectives may be subject to debate and may require further reflection and refinement. For example, will a given program prefer to generate hot-spot technologies or next-generation patents? Is it reasonable that the positioning of some R&D programs will direct them towards incremental technological improvements and away from both hotspot and next generation technologies? Additional use, analysis, and discussion of the method will help to clarify these issues.

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[25]CHI Research was bought by ipIQ and now operates as ipIQ. The developer of the hot-spot method, Anthony Breitzman, and the two other researchers who applied the method for DOE and ATP, Patrick Thomas and Diana Hicks, all formerly with CHI Research have relocated. Anthony Breitzman and Patrick Thomas are now at 1790 Analytics, and Diana Hicks is now at the Georgia Institute of Technology.

Uses:

- To identify current clusters of intensive innovative activity and developing "hot" trends in technology.
- To assess the positioning of an R&D program's output (as measured by patents and citations of the agency's publications by patents) relative to new and developing clusters of innovative activity.
- To identify the regional impact of a public R&D program in order to better organize the program's outreach activities.
- To analyze the organizational and collaborative characteristics of identified clusters of innovative activity.
- To analyze hotspots in a selected technology area (e.g., fuels, alternative vehicles, etc.) in order to assess how these hotspots and next generation patents are linked to an R&D program (e.g., EERE).
- To gather competitive technical intelligence for R&D organizations.
- To provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.

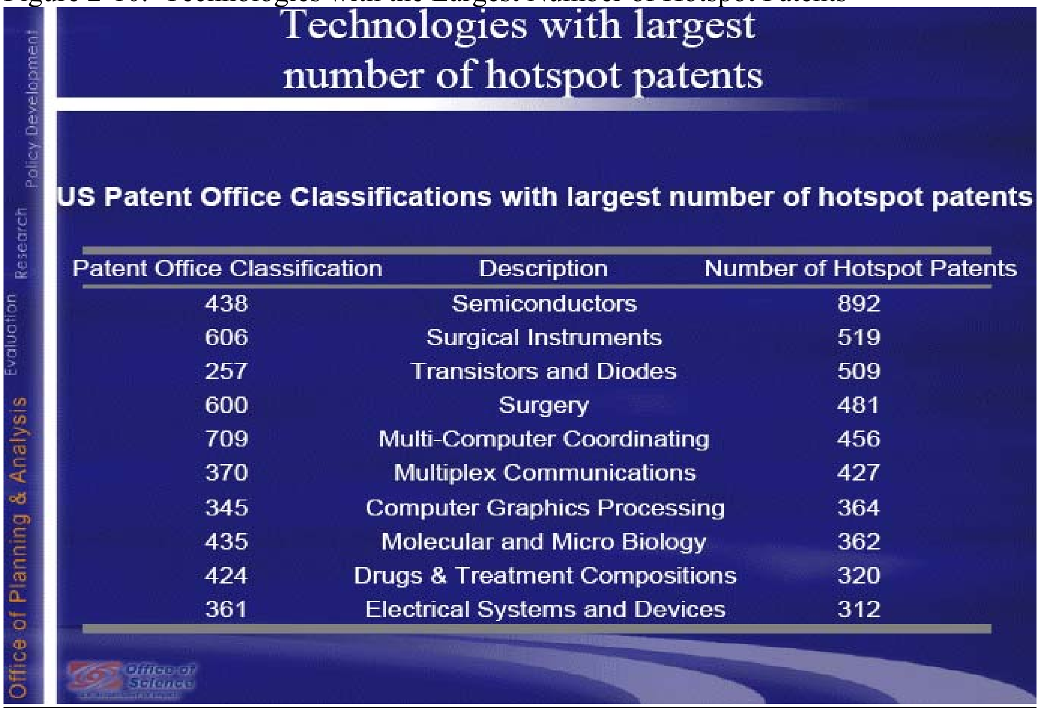
Examples: Both DOE's Office of Science and DOC's ATP have sponsored studies using the hot-spot method. Examples are given for both.

<u>Example 1: Hot-Spot technology analysis for DOE's Office of Science</u>
Building on work done in the private sector to identify investment opportunities in undervalued companies through valuations of company intellectual property portfolios and identification of "hot" technology areas, DOE sponsored use of the technique to assess and compare hot-spot results for the Office of Science and several other agencies.

Figure 2-10 shows the technology areas with the largest number of hotspot patents from all patents. Figure 2-11 shows the technology areas with the largest number of hot-spot patents that cited papers funded by DOE, NASA, NSF, and NIH.

The study found a linkage between hotspot patents and publicly funded science as indicated by funding acknowledgements in papers cited in the patents. It concluded that patents citing papers funded by publicly funded science agencies were more likely to become hotspot technologies than other patents. It found that DOE, NASA, NSF, and NIH all have strong links to hotspot patents in different technology areas, but that DOE led NASA, NSF, and NIH in the percentage of patents citing the agency's papers that became hotspot patents. Patents that cited papers funded by multiple agencies were found to be even more likely to become hotspot patents. The study also found that patents citing public science were more likely to be next generation patents than other patents.

Figure 2-10. Technologies with the Largest Number of Hotspot Patents

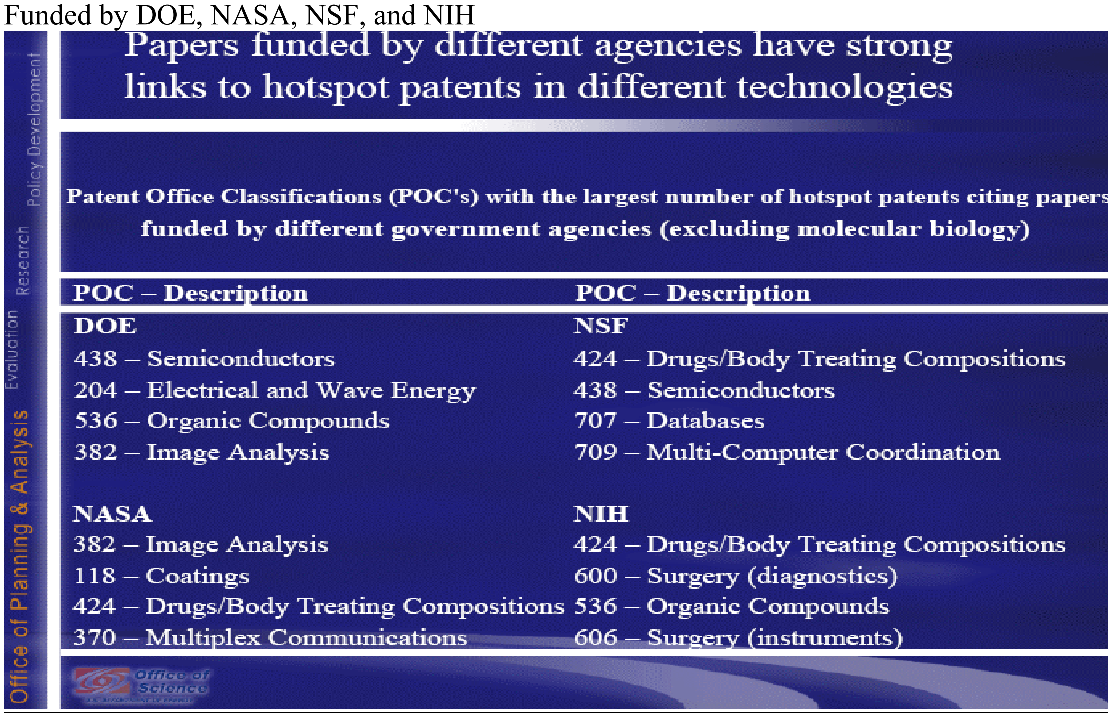

Technologies with largest number of hotspot patents

US Patent Office Classifications with largest number of hotspot patents

Patent Office Classification	Description	Number of Hotspot Patents
438	Semiconductors	892
606	Surgical Instruments	519
257	Transistors and Diodes	509
600	Surgery	481
709	Multi-Computer Coordinating	456
370	Multiplex Communications	427
345	Computer Graphics Processing	364
435	Molecular and Micro Biology	362
424	Drugs & Treatment Compositions	320
361	Electrical Systems and Devices	312

Source: Valdez presentation of March 2005, using material from a study performed by CHI Research.

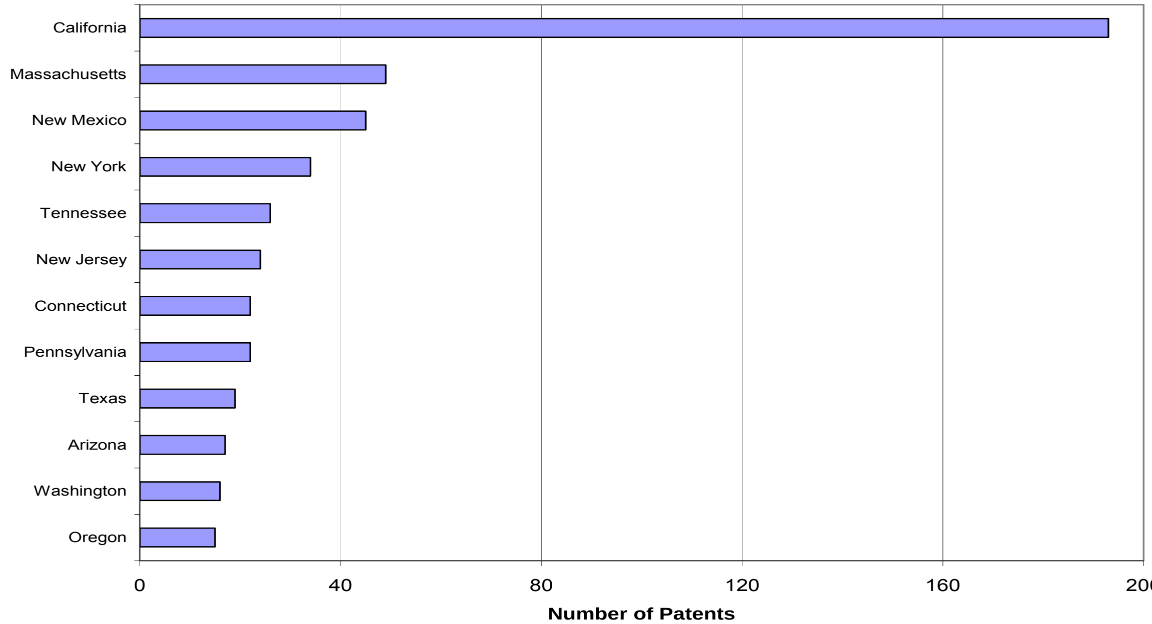
Figure 2-11. Technologies with the Largest Number of Hotspot Patents Citing Papers Funded by DOE, NASA, NSF, and NIH



Source: Valdez presentation, March 2005, using material from a study by CHI Research.

In addition, the study performed geographical analysis of hotspot patents. Figure 2-12 shows the states with the largest number of hot-spot patents linked to DOE-funded science.

Figure 2-12. States with the Largest Number of Hotspot Patents Linked to DOE-funded Science



Source: Patrick Thomas, 1790 Analytics

Example 2: Hotspot Technology Analysis for ATP

Researchers conducted a hotspot study for ATP that analyzed hotspot technologies for two time periods: 1998 and 2002. For the 1998 period, the study identified total hotspot patents numbering 10,038, next generation patents numbering 43,223, and next generation clusters numbering 2,071.

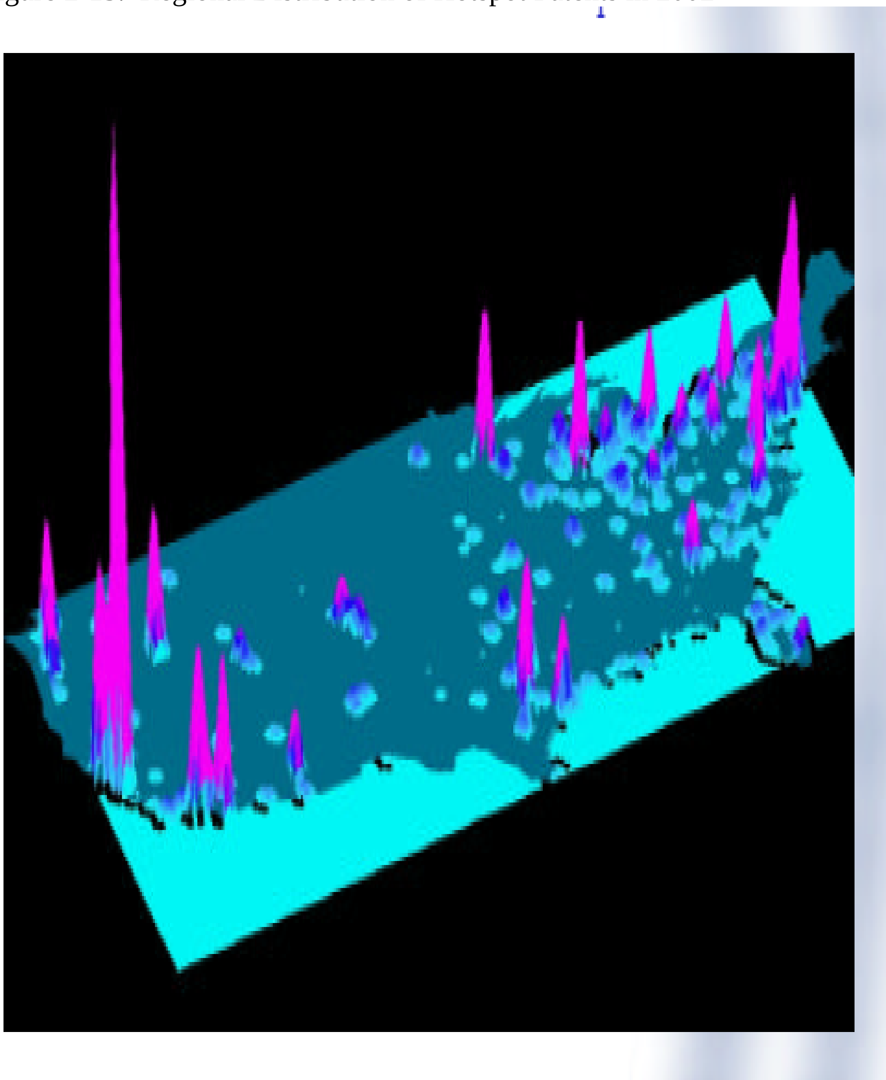
For the 2002 period, the study identified 16,451 hotspot patents, 66,216 next generation patents, and 5,455 next generation clusters. Figure 2-13 shows the regional distribution of hotspot patents in 2002.

The study, conducted by researchers Anthony Breitzman and Diana Hicks, examined patents attributed to ATP funding within the context of hotspot and next generation patents. Roughly twice the number of ATP patents was found in the next generation set than would be predicted based on a similar sized sample from the general population of patents. Forty-four percent of ATP-related patents were found in the 1998 next generation cluster and 47 percent were found in the 2002 next generation cluster, as compared with 24% in the total population.

The study's conclusion was that the association between ATP-related patents and next generation clusters is higher than would be statistically expected were not ATP's funding of technology differentiated from the norm. Clusters of next generation patents containing ATP-related patents were found to have higher than expected science linkages meaning that the ideas are closer to basic science, a high degree of public sector participation, and a high degree of multiple prior art references.

Figure 2-13. Regional Distribution of Hotspot Patents in 2002

Figure 2-13. Regional Distribution of Hotspot Patents in 2002



Source: ATP Advisory Committee presentation by Chang, May 2004, using a graph developed by Breitzman and Hicks.

References

Patrick Thomas, principal, 1790 Analytics LLC, East Gate Center, Suite 200, 309 Fellowship Road, Mount Laurel, NJ 08054 (www.1790analytics.com), provided background information on application of the hotspot method.

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U.S. Department of Commerce, Advanced Technology Program, Advisory Committee, National Institute of Standards and Technology, Minutes of the Committee, May 13, 2004, Gaithersburg, MD. (Material on the Hotspot Technology Study, performed by Breitzman and Hicks, drawn from a presentation by Connie Chang to the Advisory Committee); and "New Method for Identifying Early-Stage Technologies via Patent Analysis," a fact sheet prepared by Connie Chang, *Highlights from ATP's Economic Studies, Factsheet 1.C.7.* (The fact sheet provides highlights in advance of ATP's publication of the hotspot research report (in press), by Anthony Breitzman and Diana Hicks.)

2.6 Network Analysis

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. Design/revise, plan, select, budget
2. **Make R&D progress, review processes, achieve outputs**
3. **Disseminate outputs, achieve interim outcomes**
4. Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts

Information Provided by Evaluation Methods:

- **Planning information**
- **Indicators of interim progress**
- **Analysis of collaborative and other relationships**
- **Creation and dissemination of knowledge outputs**
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- Spillover effects
- Comparative standing
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

Network analysis, which shows linkages among researchers or organizations and how they develop over time, is useful in assessing a program's impact on collaboration and emerging roles and positions of influence of researchers and organizations. While bibliometric methods show how knowledge is disseminated via citing publications and patents, network analysis shows how knowledge—particularly tacit knowledge—is disseminated via a variety of communication flows. Development of research networks is significant because it is expected to increase research capabilities, progress, and impacts.

Definition: Known variously as "Social Network Analysis" (SNA), "Organizational Network Analysis," (ONA), or just "Network Analysis" (NA), this is a method of visually mapping and measuring relationships and linkages among researchers, groups of researchers, laboratories, or other organizations. Network analysis is relevant to evaluation of R&D programs because it identifies routes of interactions by which ideas, knowledge, and information flow among participants in R&D, thereby possibly influencing the nature, quality, quantity, and speed of research and innovation, as well as the dissemination of created knowledge through the network. The underlying concept is that the conduct of science is a social activity collectively performed and resulting in "communities of practice." Advances in knowledge stem from knowledge sharing and knowledge combining activities. Networks can link researchers to a rich flow of ideas and information. A network of researchers creates a knowledge system that may yield much more than the individuals acting independently. The network analysis method, which examines flows of knowledge into and through the social network, is seen as a promising approach to understanding, predicting, and improving knowledge outcomes. Network shape, size, and density can serve as indicators of the strength of communities of practice and signal relative roles and relationships.

How network analysis studies are organized, conducted, and analyzed: Researchers, research groups, and other entities in a network are denoted as nodes. The relationships or flows between entities are called links, denoted as lines linking the nodes. Arrows show the direction of the relationship (incoming arrows show that the node is a source of information and outgoing arrows show the node seeks information from the linked node). Characteristics of the communication flow or outputs such as e-mails, face-to-face contacts, papers and patents generated can be indicated on the lines linking the nodes. A sequence of links from one node to another is called a path. Data for diagramming networks are collected in a variety of ways, such as by conducting interviews or surveys, tracking e-mail flows, observing interactions, assessing co-authorship, and analyzing resumes of researchers. To analyze results of network analysis, several measures are used. One measure is of centrality, based on the number of direct links one node has to other nodes. Another measure indicates the extent of influence a node has over flows in the network to other nodes. A third measure indicates how closely linked a nodule is both directly and indirectly to all other nodules in the network. An entity in a network may be a "hub," i.e., a node with a high degree of centrality and also important as a link to other parts of the network. An entity may be a "peripheral player," a node on the periphery of an identified network. It may be a "boundary spanner," a node connecting one network cluster to another. "Clusters" may develop within networks, i.e., groups within the network connected through multiple links. Analysis of networks can reveal areas of potential failure, such as the vulnerability of a highly centralized network to the departure of a key researcher. It can also reveal areas of strength, such as clusters with connection redundancies that make them less vulnerable to removal of single links or nodes. The density of a network that develops around research entities may signal their relative importance. Network software packages are available for assisting with the drawing of network diagrams and computation of measures.

Limitations: While a network diagram and analysis can reveal the extent of collaboration and may suggest the importance of a program's R&D to others, it does not provide a quantitative measure of its value. A network diagram may be time limited: it shows the relationships as of a specific point in time, such that repeating the process after a time interval is necessary to reveal changes in the network over time. Costs can be a limiting factor in the use of network analysis because determining networks can require many interviews or time-consuming analysis of resumes, or the like to trace the network, particularly if the evolution of a network is traced across time and takes into account both formal and informal connections..

Uses:

- To analyze the impact of R&D policies on collaborative activity.
- To reveal dominant researchers or research organizations, and/or to assess the openness of networks to new members.
- To improve understanding of how and why collaborations develop, what form they take, and their dynamics.

- To investigate and demonstrate the impact of an R&D program on applications by examining the flow of knowledge among researchers, groups of researchers, and users.

- To identify and foster emergent knowledge systems; to assess their strengths and weaknesses.

- To highlight the importance to participants of intangible asset development, and to assess more fully knowledge spillovers.

- To provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.

Examples: Two examples of network analysis are provided below. The first example illustrates primarily the first and second listed uses. The second example illustrates primarily the third and fourth listed uses. To some extent, both examples also illustrate the other uses listed.

<u>Example 1: Using network analysis to examine the impact of R&D policy on collaborative activity and to assess network access by new members</u>

The European Commission's Sixth Framework Programme (FP6, 2002-2006) had a goal of promoting denser and more diverse research collaborations. Although it will be years before the impact of FP6 on economic growth is known, and many months before outcomes such as patents granted, products, papers, and participation can be assessed, it is possible now to examine patterns of collaboration and evaluate the impact of FP6 on research networks in Europe. A recent paper describes an evaluation of research networks created by FP6 calls 1 and 2.[26]

The study was conducted to gain insights into the degree to which Information Society (IST) researchers were collaborating and the impact of the new FP6 Instruments on the integration of IST research. The study also developed and refined tools and datasets for the analysis. It assessed six research areas, known as "Strategic Objectives," within the European Commission's research IST Thematic Priority, using three types of analysis: network structure analysis, content analysis of the types of participants in the network, and value analysis based on survey data to understand the motivations of participants for joining the networks.

The study found that the Framework Programme (FP) has provided a major integrating function and has created an intensely linked network of IST research collaborations in Europe. The funding has helped to connect universities and businesses, connect researchers in different sectors and disciplines, integrate new member states into collaborations, integrate key patent-holders, and integrate small businesses. The study found that FP6 resulted in increasing the interconnectedness of network participants more than the previous FPs did. The study raised the concern that large institutes and companies act as "gate-keepers" to Framework participation, and, that while providing stability over time, this may have had a crowding-out effect on small and medium establishments. The study also found that a strong motive for participation in the F6 networks was to obtain improved capabilities, tools, methods, or techniques, relationships, and access to world-class knowledge, i.e., intangible asset development, rather than to develop new products and services.

[26] Cunningham and Wagner, October 2005 and November 2005.

Example 2: Using network analysis to understand the dynamics of collaborative activity and to investigate and demonstrate the impact of science on applications

The Department of Energy sponsored social network analysis conducted by researchers at the University of Southern California to investigate the flow of knowledge through networks of DOE scientists in order to pursue the following three research questions: (1) what approaches to modeling a network are useful for displaying and analyzing the flow of value within and from the network, (2) what are the attributes of a research network that facilitate the flow (leverage) of value through the network, and (3) what organizational features facilitate forms of network?[27]

Of two studies conducted to date, one examined a research network that evolved over 16 years, beginning in 1987. The research aimed at developing and evolving the capacity to use Massively Parallel Processing (MPP) to do large-scale scientific and engineering modeling and simulation. Early, multi-disciplinary work on MPP involving break-through research in mathematical computations and computer science demonstrated that MPP could be used to solve complex scientific problems. The work was centered at Sandia National Laboratories.

The study's data collection methods included a survey to define collaborations, identify sources of knowledge, and define the value of knowledge flowing through links. Data collection methods also included interviews to compile qualitative data to inform the history of and activities in the subject network, the nature of collaborations, and organizational features. In addition, the study analyzed archival material (resumes) to assess demographic attributes. Beyond network depiction and measurement, the study used qualitative case analysis and multivariate analysis as complementary methods to deepen the analysis.

In addition to the standard knowledge/communication network questions, i.e., who gets knowledge from whom and who talks to whom, the study focused on the extent and kinds of collaboration in the network, as well as the type of knowledge passed among members of the network, its value as judged by the recipient, and how critical the knowledge was to the work of the survey respondent. Respondents were asked to choose among answers a-c: The knowledge was (a) helpful learning but did not contribute directly to their solving the problem; (b) provided content information and/or methodological information that influenced the way they approached the problem and/or expedited the process of moving to solution; or (c) was critical in determining the way they approached and solved the problem and/or was able to be incorporated into their work.

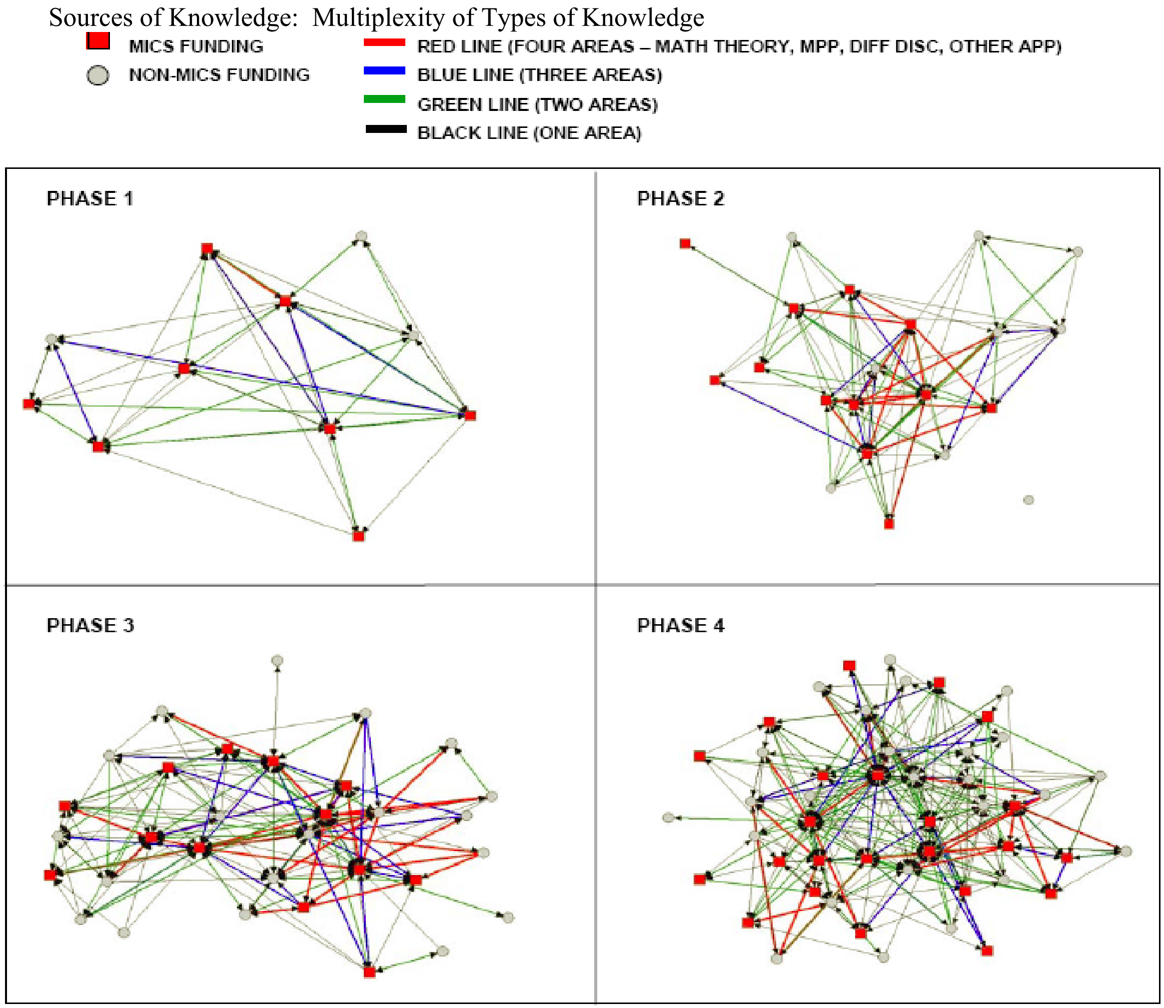
Figure 2-14 shows the "sources of knowledge" network -- one of many network diagrams produced by the study. The colored lines indicate the multiple kinds of knowledge flowing across the same link: 1) mathematical theoretical knowledge; 2) MPP methodological knowledge; 3) knowledge from a different basic discipline; and 4) knowledge about the application.

Study findings centered on identifying the dynamic networks, the organizational conditions for self-forming networks, and the organizational conditions facilitating the flow of knowledge. Among the MPP case study's findings, the following are illustrative of those concerning dynamic networks: (1) Network connections were found to be self-forming. (2) Network connections stretched across multiple labs within Sandia, across multiple national laboratories across the

[27] Mohrman, Galbraith, and Monge (2004).

country, and across multiple universities and corporations. (3) The networks followed lateral lines, and had little operational contact with the hierarchical dimension of the organizations. (4) As the work proceeded through phases, the nature of the knowledge and structure of the knowledge network changed to fit the task.

Figure 2-14. Examining Network Connections in Four Phases of Activity of The Development: (1) The First Test Adopter, (2) Early Adopters, (3) Wide-spread Adoption, and (4) Focus on Capability Development.



Note: MICS is the Applied Math Directorate in the DOE Office of Science.
Source: Mohrman, Galbraith, and Monge, 2004.

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Susan A. Mohrman, Jay R. Galbraith, and Peter Monge, *Network Attributes Impacting the Generation and Flow of Knowledge within and from the Basic Science Community*, funded by Sandia National Laboratories and the Office of Science, 2004.

Caroline S. Wagner and Frank Cunningham, "The Critical Link: Evaluating Research Dynamics Using Network Analysis," APPAM Meeting, November 2005. View at www.appam.org/conferences/fall/dc2005/sessions/downloads/0642.doc.

2.7 Case Study Method

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. **Make R&D progress, review processes, achieve outputs**
3. **Disseminate outputs, achieve interim outcomes**
4. Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts

Information Provided by Evaluation Methods:

- **Planning information**
- Indicators of interim progress
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- **Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures**
- Spillover effects
- Comparative standing
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

Case studies use narratives supported by data to describe, explain, and explore phenomena and events. Case studies are a particularly useful strategy for addressing how and why questions within a real-life context. For example, case studies can be used to shed light on how innovation occurs, why certain decisions are made, and why some processes work better than others.

Definition: The case study method presents information through a narrative about the subject, often with supporting data displayed in tables and graphs. Case study is a method widely used by R&D programs for evaluation—both to describe programs and how they work and to investigate underlying functional relationships. One reason for its widespread use is that the narrative can often capture the richness of detail and complexities of scientific research and development—particularly for a non-scientific audience, while quantitative results can be often be provided with little additional effort. Another, related reason is that case studies put meat on the bones of statistics and deepen stakeholder understanding of the subject of inquiry. The case-study narrative provides context and explanation for accompanying quantitative findings. Case studies for evaluation are distinguishable from "success stories" used by most programs in a public relations mode in terms of their comprehensive treatment of all aspects of their topic—both positive and negative.

How case studies are organized, conducted, and analyzed: Case studies may be conducted as single, stand-alone products, or as a body of work consisting of multiple cases. The information used to develop a case study often comes from multiple sources, such as interviews, direct observations, existing databases, and literature searches. In addition, results from studies using other evaluation methods may inform case studies, just as case studies may inform studies using other evaluation methods. When conducting a body of comparable case studies, analysts typically look for common themes and emergent trends, patterns, and explanatory factors. Analyses of cases often lead to the identification of potential issues or the formulation of theories or hypotheses about program or process dynamics that can be formulated for further testing using other, more quantitative methods. Emphasis in a case study is typically on the narrative, with quantitative results in a supporting role, but there is often a strong mix of the two.

As with applying the other methods, undertaking a case study requires a research design. A useful starting point is to define the proposition(s) of interest and an initial set of questions to be asked and answered to identify the relevant information. The next step is to identify the unit(s) of analysis, such as a person, company, program, organization, or groups of persons, companies, programs, and organizations. The next step is to develop an action plan for collecting, analyzing, and interpreting observations. Development of an interview guide is recommended for conducting interviews, particularly when multiple cases are to be undertaken, to help stay focused on the topics of interest and to replicate topical information. Case studies that are exploratory in nature will generally be less structured than cases that are descriptive or explanatory, but a hallmark of all case studies is to take advantage of unexpected opportunities while keeping firmly in mind the issues under study. Carrying out the information collection phase and writing case-study results demand an experienced investigator and writer. The case study investigator and writer should have a good grasp of the issues being studies and should be unbiased—equally responsive to supportive and contradictory evidence regarding the issues being studied.[28]

There is no single format, rather there are a variety of formats or structures which may be used for writing case-studies. One format is the chronological structure, reflecting cases that cover events as sequences over time. Descriptive case studies are often presented using key areas of information as subtopics, such as the origin of a research idea, the source of technology, the role of government, estimated sales, etc. Exploratory and explanatory case studies may present a series of hypotheses, followed by what the case or cases show. A linear-analytical structure is one of several other alternatives, whereby the purpose of the study is followed by the methodology, the findings from information collected and analyzed, and then by conclusions.

Limitations: A principal limitation of the case study method is that to the extent that it provides anecdotal evidence rather than quantitative evidence, it is generally considered less persuasive than, for example, more comprehensive statistical approaches. Furthermore, it may be difficult to generalize from descriptive case study results; other cases may show other results. However, if sufficient representation of a population is provided through case study and through supporting quantitative results, it may be possible to draw common themes from case studies that can be generalized to a population.

Uses:
- To explore the genesis of research ideas and their consequences.

[28] Yin, 1994.

▪ To tell the stories of the people, organizations, projects, and programs involved in scientific pursuit.

▪ To investigate underlying theories and explore process dynamics.

▪ To answer specific what, why, and how questions.

▪ To provide illustrative examples of how a program works.

▪ To provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.

Examples: Examples of use of case study by agencies and other organizations as a component of evaluation abound. Three examples are given to illustrate three different uses of case study, emphasizing the versatility of the method. The first example demonstrates the use of case study primarily for exploration—in this case to search for factors underlying success in research collaborations. The second example demonstrates the use of case study primarily for description—in this case to describe the short-run outcome status of a set of publicly funded projects after government funding has completed. The second example also demonstrates that case study can combine narrative and data collection. The third example demonstrates the use of case study primarily for explanation—in this case to explain how a sample of firms use Small Business Innovation Research (SBIR) grants to develop their businesses through innovation and commercialization.

Example 1: Using case study to explore factors important to collaborative relationships
Researchers performed cases studies of 18 joint ventures co-funded by the Advanced Technology Program and undertaken in the automotive industry between 1991 and 1997. The purpose of the case study was to explore determinants of success in the collaborative activities.[29] Two measures of joint venture success were defined: (1) whether the project achieved its technical objectives, and (2) whether it produced a commercializable technology or product. The cases were performed using informal interviews with participants in each of the joint ventures.

Among the case study findings were the following: (a) Increased trust and information sharing among joint venture members was associated with joint venture success. (b) Experience working together prior to the formation of the joint venture was associated with success of the joint venture. (c) Vertically structured joint ventures in which members provide complementary goods and services appear easier to manage than horizontally structured joint ventures whose members provide competitive goods and services. (d) Joint ventures can have too many or too few members for effective collaboration. (e) Stability of joint venture participants increases the likelihood of success. (f) Co-location increases the likelihood of success.

The evaluators also looked at the contribution of the government program to collaborative success. The program's contribution took several forms, such as by requiring more commitment from top management of joint venture participants upfront, by using the program's application process to

[29] Dyer and Powell, 2001.

foster goal-directed and well organized joint-venture projects, and by helping to overcome specific barriers to collaboration.

The case studies also suggested that collaborations organized in response to the government program are fostering expanding networks of experts with technical skills and know-how that appear to be leading to improvements in products or processes outside the context of the government-funded projects.

Example 2: Using case study to describe the outcome status of a set of publicly funded projects, including systematic collection of supporting data
The selected example illustrates the extensive use of descriptive case study (in combination with the systematic collection of indicator data) to provide progress reports on all completed R&D projects funded by the Advanced Technology Program about four years after completion of each research project. Each case study, which is approximately 3-5 pages in length, captures in narrative form a funded technology and its development, the role played by ATP, technical and business accomplishments to date, and the outlook for future progress. Data for key project inputs, outputs and outcomes are systematically collected and aggregated to provide interim performance metrics for use by the program. These include numbers of publications, patents, prototypes, commercial products in the market and expected soon, employment effects, and awards received from third-parties in recognition of scientific accomplishment and business acumen.

One hundred of these descriptive cases for ATP's completed projects in a variety of technology fields had been completed at the time of this report. They can be viewed online at www.atp.nist.gov/eao/eao_pubs.htm, by selecting "Status Reports" at the top selection bar. The set of project case studies includes all levels of project performance, ranging from poor to outstanding based on success criteria. A four-star rating system,[30] based on the collected case-study metrics, is used to score the performance of each project and to show the distribution of project performance across the portfolio of completed projects. In this way, the system bridges from project case study to portfolio management.

Example 3: Using case study to explain how firms use Small Business Innovation Research (SBIR) grants to develop their businesses through innovation and commercialization
The National Research Council (NRC) included a large set of descriptive case studies as part of its assessment of the SBIR program at five U.S. government agencies having the largest SBIR programs, namely the Department of Defense, National Institutes of Health, Department of Energy, National Aeronautics and Space Administration, and National Science Foundation. A set of case studies was prepared for each agency's SBIR program to supplement survey results and other methods used to assess the program.

The case studies help to explain how small companies use the SBIR program to obtain early seed capital to launch technologies—and often their businesses—and expand innovative capacity and intellectual property portfolios. The case studies discuss company financing and commercialization strategies, the outcomes of sample SBIR-funded projects, and summarize the

[30] For an explanation of the 4-star rating system, see Ruegg, 2006.

views of company officials on the SBIR program. They help explain variations among the SBIR program at these agencies.

These case studies will be presented as an important component of each of a series of five reports the NCR is preparing on the SBIR program at each of the five agencies listed above. These reports are expected to be published late in 2006.

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2.8 Survey Method

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. **Make R&D progress, review processes, achieve outputs**
3. **Disseminate outputs, achieve interim outcomes**
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- **Planning information**
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- **Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures**
- Spillover effects
- Comparative standing
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

A survey collects information by asking people questions—the answers to which can be expressed in terms of statistics. This method is particularly useful for characterizing a program's progress, learning more detailed information about that progress, assessing customer satisfaction, and answering a variety of stakeholder questions.

Definition: Survey is a method of obtaining information directly from people about their ideas, opinions, attitudes, beliefs, preferences, concerns, plans, experiences, observations, and virtually any other issue. A survey collects information by asking people questions and recording their responses. Surveys are often used when the desired data are not available through other sources, but could be obtained by asking people. Surveys are used in R&D evaluation for a variety of purposes, such as learning about a program's progress and effects; discovering the opinions of those participating in a program or using its outputs; addressing stakeholder questions; and gathering information to supplement other sources of information.

How survey studies are organized, conducted, and analyzed: Given that surveys obtain information from people, it is necessary to decide which people and how many people to ask; what to ask; how to structure the questions; when and how often to ask; and how to submit the questions—all aspects of survey design. Using samples reduces study costs, but if a sample is too small, it may not adequately represent the population of people it is intended to represent. A survey may be administered just once to a given group to obtain data as they exist at that time, in which case it is "cross-sectional." Alternatively, a survey may be administered to the same group of people at different times to assess changes over time within the group, in which case it is "longitudinal." Alternatives for administering a survey include paper copies or computer disks, electronic copies sent via e-mail or web-based, questions asked by an interviewer face-to-face or by telephone. If a survey is administered in person or by phone, a decision must be made about who will conduct it. Questions asked may be open-ended or may have forced choices. A balance must be struck between collecting needed data and avoiding being overly intrusive or imposing too much burden. Survey data are commonly analyzed using descriptive statistics, such as counts, percentages, averages, ranges, and measures of central tendency and measures of variation. Survey data may also be analyzed to show relationships, to compare groups, and to determine trends and changes over time. Fortunately, there are many text books and references that provide detailed guidance on all aspects of survey design and there are many experienced practitioners of this method.

Limitations: Limitations—such as failure to adequately reflect the target population or biases in the results—typically arise from weaknesses in survey design. To help eliminate these weaknesses up front, detailed review of all aspects of a survey's design, together with pilot testing—i.e., administering the proposed survey to a small sample of people who are the same as those who would be included in a full-scale survey—are advised. Still, low response rates may limit the reliability of results and may require extra steps to increase responses. Costs can be an issue, in that a survey not only imposes costs on the sponsor of the survey, but also on those surveyed. This potential burden is recognized in Federal government by the Federal Paperwork Reduction Act which limits the ability of a Federal program to administer surveys to 10 or more people without prior OMB approval, which can be a lengthy procedure. It is also worth noting that the survey method is a means of obtaining, analyzing, and releasing aggregate responses; individual responses are understood to be treated as confidential without the explicit agreement of the respondent to the contrary.

Uses:

- To describe a program statistically.
- To assess customer satisfaction.
- To answer stakeholder questions about a program and its effects.
- To support evaluation studies.
- To provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.

Examples: Survey is a mainstay of evaluation for many Federal programs, as well as many other organizations, and potential examples abound. Four examples of how organizations use the survey method follow. The first illustrates descriptive program data. The second illustrates customer or user satisfaction data. The third and fourth examples both illustrate the use of survey to provide evidence that a Federal R&D program caused observed impacts and did not merely substitute taxpayer money for private sector funding, but with an essential difference in the two examples: One uses counterfactual questions to find out what participants would have done if they had not received program funding. The other uses a comparison group to find out what actually happened to those that did not receive program funding. The latter example is considered to provide stronger evidence of impact than the former.

Example 1: Using survey for statistical description of a program's knowledge outputs

The National Academy of Sciences has recently used survey extensively in its congressionally mandated assessment of the SBIR program at five agencies. In support of the study, cross-sectional surveys were conducted for a sample of projects funded by Phase I and Phase II grants and of grant recipients. (A series of agency reports that include survey results is forthcoming from NAS press.[31]) Table 2-7 shows, for illustrative purposes only, preliminary descriptive survey results for just one of the many questions included in the survey, and for just one of the agencies for which survey data were obtained.[32]

Table 2-7. Survey Results on Intellectual Property Generated by a Sample of 151 Phase II SBIR-Funded R&D Projects: Sample Averages

Type	Average Number Applied for/Submitted	Average Number Received/Published
Patents	1.05	0.67
Copyrights	0.32	0.28
Trademarks	0.28	0.22
Scientific Publications	1.76	1.66

These descriptive survey statistics indicate that scientific and technical knowledge was generated by the sample of SBIR projects, and they show various forms in which the knowledge was disseminated. Average knowledge outputs per project may be useful for making comparisons against those of other, similar R&D programs.

Example 2: Using survey to find out what customers/users want

The second illustration, shown in Table 2-8, is from a user satisfaction survey conducted annually by the DOE National Energy Research Scientific Computer Center (NERSC). The survey aims to "provide feedback about every aspect of NERSC's operation, help us judge the quality of our services, give DOE information on how well NERSC is doing, and point us to areas we can improve." A 7.00 point rating scale was used to assess user satisfaction. The average satisfaction scores from the 2003 survey ranged from a high of 6.61 (very satisfied) to a low of 4.67 (somewhat satisfied). The upper part of the table shows areas of highest user satisfaction and the lower part, areas of lowest user satisfaction.

[31] See, for example, Committee on Capitalizing on Science, Technology, and Innovation: An Assessment of the Small Business Innovation Research Program, *Project Methodology*.

[32] The data are preliminary and used only to illustrate the survey method; further identification of the source is not provided pending publication by NAS of study results.

Table 2-8. NERSC User Survey, 2003, Illustrative Results

Areas with the highest user satisfaction:

Topic	Avg Score	No. of Responses
HPSS reliability	6.61	126
Consulting - timely response	6.55	207
Consulting - technical advice	6.54	200
HPSS uptime	6.54	126
Local Area Network	6.54	114

Areas with the lowest user satisfaction:

Topic	Avg Score	No. of Responses
Access Grid classes	4.67	27
Escher visualization software	4.75	8
Visualization services	4.81	97
NERSC training classes	4.88	24
Training	5.04	94

According to the survey report, the results trigger changes at NERSC that are intended to improve performance and raise user satisfaction. Yearly changes are tracked.

<u>Example 3: Using survey supported by counterfactual questions to provide evidence that a government program has impact</u>

One survey design approach sometimes used to provide evidence of program impact is a non-experimental design with counterfactual questions to learn from participants what they think would have happened had the government program not existed. Counterfactual questions typically entail asking survey respondents several hypothetical questions: Would they have proceeded with their research project had they not received government funding for it? If they would have proceeded without government funding, would the project have been different? Table 2-9 shows responses to these questions for the first 50 completed projects funded by the Advanced Technology Program (ATP). The results were used as one line of evidence of program impact.

Table 2-9. Survey Responses to the Counterfactual Question, "What would have happened without the ATP award?"

Alternatives	Percent Reporting the Effect (%)
Without the ATP funding: - We would not have proceeded with the project	59%
Without the ATP funding we would have proceeded but with a delay:	41%
- 6 months	2
- 18 months	9
- 21 months	7
- 24 months	11
- 5 years or more	9
- unspecified	2

Source: ATP, Status Report No. 2, 2001.

<u>Example 4: Using survey supported by a comparison group to provide evidence that a government program has impact</u>

A later ATP survey used a quasi-experimental design with a comparison group. This approach was used to test if non-winners (of ATP R&D funding) continued with their proposed research projects, and, if so, what was changed from the plan submitted to ATP. In other words, rather than ask winners the counterfactual question, "what would they have done if they had not won," this approach asked a group of applicants who did not win what they actually did. Table 2-10 shows the extent to which the non-winners said they actually pursued the proposed R&D. The question was asked a year after they failed to receive the award while the experience was still relatively fresh and could more likely be recalled by respondents.

Table 2-10. Survey Responses Indicating What Companies Who Did Not Receive Federal Funding Actually Did Regarding the Proposed Project

Did not proceed with the project, at any scale	62%
Began project on a much smaller scale than that proposed	17%
Began project on a somewhat smaller scale than proposed	12%
Began project at about the same scale as proposed	5%
Began project on a somewhat larger scale than proposed	3%
Began project on a much larger scale than proposed	1%
Number of Cases	168

While both survey studies sought essentially the same kind of information about the role played by program funding, the second approach, which included a comparison group, is considered more rigorous than the approach that relied on counterfactual questions. ATP program management used the results of the comparison group study to inform an NAS assessment of the program and to provide stronger evidence for PART of the program's impact.

References

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Feldman and Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in the National Research Council report, *The Advanced Technology Program: Assessing Outcomes*, (Washington, DC: National Academy Press, 2001).

Fowler, F.J., *Survey Research Methods*, 3rd Edition (Newbury Park: Sage Publications, 2001.)

National Research Council, Committee on Capitalizing on Science, Technology, and Innovation: An Assessment of the Small Business Innovation Research Program, *Project Methodology* (Washington, DC: The National Academies Press, 2004.) Other reports on The Small Business Innovation Research Program that include survey results are expected to be forthcoming in 2006.

U.S. Department of Energy, National Energy Research Scientific Computer Center (NERSC), *FY 2003 Survey Results*, available on-line at www.nersc.gov/news/survey/2003/.

2.9 Benchmarking Method

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. Make R&D progress, review processes, achieve outputs
3. Disseminate outputs, achieve interim outcomes
4. Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts

Information Provided by Evaluation Methods:

- **Planning information**
- Indicators of interim progress
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- Spillover effects
- **Comparative standing**
- Overview – was it worth it?

[Goals, phases, and information provided by this method are highlighted]

Benchmarking means making comparisons to see how people, programs, organizations, regions, or countries compare in terms of some aspect of their performance—to identify where and how to make improvements.

Definition: Benchmarking is the systematic comparison of practice, status, quality or other characteristics of programs, institutions, regions, countries, or other entities using a selected set of performance measures. It serves to compare the performance of R&D labs with counterpart labs in selected fields and sub-fields, across sectors and across national borders. Organizations use benchmarking to measure and compare various aspects of their practices, such as costs, productivity, resource allocation, staffing levels, skill sets, R&D management practices, R&D leadership, and evaluation practices against those of other organizations and against established standards.

How benchmarking studies are organized, conducted, and analyzed:
Benchmarking requires deciding what entities are to be compared, what aspects of those entities are to be compared, and how the comparison will be made. Variation among Federal R&D programs and among agencies means that an agency that wishes to use benchmarking will need to tailor its approach. For some limited comparisons, one or more performance indicators may be used, such as budgets to compare the size of R&D programs. For broader comparisons, such as

research leadership, quantitative performance indicators alone may be inadequate and the judgment of experts may be needed.[33]

Limitations: Determining how programs, agencies, or countries compare in R&D typically involves a great deal of data, as well as judgment. If benchmarking is performed on broader topics, such as scientific leadership, but based on limited quantitative indicators, such as papers cited, problems may arise because the indicators are inadequate to measure performance at the level desired. Benchmarking provides a time-dependent snapshot of performance of an R&D area; at the same time, changes are likely to occur too slowly to detect by frequent (annual) benchmarking.

Uses:

- To determine how a program's/agency's/region's/country's performance compares with that of others.

- To determine the leadership status of a program/agency/region/country in one or more fields or sub-fields of science.

- To identify best practices used by others in order to improve one's own performance.

- To provide information that may help guide administrators, policy makers, and funding agencies to make Federal research decisions.

Example: The example illustrates benchmarking in the first three uses listed above. It is for a landmark study conducted by the National Academies Committee on Science, Engineering and Public Policy (COSEPUP**)** to test the benchmarking method for comparing U.S. leadership with the rest of the world in selected research fields. (For an example of a much more modest benchmarking effort—comparing evaluation methods among programs, see Table 1-1 in Part 1 of this booklet and accompanying reference.)

To conduct the study, the committee first established an oversight group including people with broad backgrounds who selected three fields for the R&D benchmarking experiment: mathematics, immunology, and materials science and engineering. The oversight group also preliminarily defined sub-fields and selected expert panels in each field. Panel members included U.S. experts in the research field, experts in related fields of research, non-U.S. experts in the field and related fields, users of research results, and, for each panel, an expert in policy analysis. Each panel was asked to answer the following three main questions: 1. *What is the position of U.S. research in the field relative to that in other regions or countries*? 2. *On the basis of current trends in the U.S. and world-wide, what will be the relative position of the U.S. in the near and longer-term future*? 3. *What are the key factors influencing relative U.S. performance in the field*?

The panels of experts revisited the sub-fields and were free to modify them. They divided sub-fields into sub-sub-fields, e.g., the field of immunology was divided into four major sub-fields,

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[33] In the context of the Government Performance and Results Act (GPRA), the National Academy of Sciences Committee on Science Engineering, and Public Policy (COSEPUP) recommended that agencies whose missions include the goal of world leadership in a scientific field consider using international benchmarking with expert panels to judge research quality, relevance, and leadership status.

and each of the sub-fields into four-to-10 sub-sub-fields. The panels used a variety of methods to assess each sub-field, including the following: The virtual congress method, citation analysis, journal-publication analysis, quantitative data analysis, prize analysis, and international congress speakers.

The virtual congress method had the panel identify the "best of the best" researchers in the world in each sub-field, and then asked these researchers to imagine themselves as organizers of a session in their field and to furnish a list of desired speakers. Citation analysis compared each country's citation rate for a field to the worldwide citation rate for that field. Journal publication analysis had the panel identify leading journals in the field, scan their table of contents, and perform a quantitative comparison of publications by U.S. and non-U.S. researchers. Quantitative data analysis had the panels attempt to locate unbiased information for comparing major features of the scientific enterprise—reportedly a problematic effort. The prize analysis method had the panel identify the key international prizes in its field and analyze the numbers of U.S. and non-U.S. recipients of these prizes in terms of their current residence status. The international congress speakers method had the panel analyze actual representation at topical international conferences by U.S. and non-U.S. speakers. Reportedly, they were able to determine which measures worked best for comparison for each field.

Each panel issued a report benchmarking its field. Each panel identified sub-fields in which the U.S. lagged the world leaders, but concluded that the U.S. was at least among the world leaders in each of the broader fields.

As summarized in Tables 2-11 and 2-12, the panels identified institutional and human-resource factors critical to maintaining leadership status in a field. Panel members also concluded that the benchmarking approach was "rapid and inexpensive compared with evaluation procedures that rely solely on the assembly of a huge volume of quantitative information."[34]

Table 2-11. Factors Influencing U.S. Leadership Performance

Factors considered most important	Fields in which the factors were deemed most important		
	Mathematics	Materials	Immunology
Human resources and graduate education	X	X	X
Funding	X	X	X
Innovation process and industry		X	X
Infrastructure		X	X

[34] National Academy of Sciences, 2000. .

Table 2-12. Factors Expected to Influence the Future Position of U.S. in Research

Factors expected to be most important	Fields in which the factors are expected to be most important		
	Mathematics	Materials	Immunology
Intellectual quality of researchers and ability to attract talented researchers	X	X	X
Ability to strengthen interdisciplinary research	X	X	
Maintenance of strong research-based graduate education	X	X	X
Cooperation among government, industrial, and academic sectors		X	

References

Diana Hicks, Peter Kroll, Francis Narin, Patrick Thomas, Rosalie Ruegg, Hiroyuki Tomizawa, Yoshiko Saitoh, and Shinichi Kobayashi, *Quantitative Methods of Research Evaluation Used by the U.S. Federal Government*, NISTEP Study Material, No. 86, May 2002, available on-line at www.nistep.go.jp/achiev/ftx/eng/mat086e/idx0863.html.

National Academy of Sciences, Committee on Science, Engineering, and Public Policy (COSEPUP), Experiments in International Benchmarking of US Research Fields (Washington, DC: National Academy Press, 2000), available on-line at www.nap.edu/books/0309068983/html.

U.S. House of Representatives, Science Subcommittee on Basic Research, "What Can It Tell Us?" Hearing Report, October 4, 2000.

2.10 Technology Commercialization Tracking Method

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. Design/revise, plan, select, budget
2. Make R&D progress, review processes, achieve outputs
3. Disseminate outputs, achieve interim outcomes
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- Planning information
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- **Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures**
- Spillover effects
- Comparative standing
- **Overview – was it worth it?**

[Goals, phases, and information provided by this method are highlighted]

Technology commercialization tracking involves monitoring technologies considered to be commercially successful and their associated energy savings, economic and environmental benefits. Market and cost data is used to estimate the cumulative net benefits of the program.

Definition: The technology commercialization tracking method tracks the new, energy-efficiency technologies developed through R&D projects sponsored by the program and that may include research cost-shared with industry. It classifies those technologies showing a requisite level of development, such as either "emerging," "commercially successful," or "mature." For example, a technology could be considered emerging when it is thought to be within approximately one-to-three years of commercialization. It could be considered commercially successful when full-scale commercial units of a technology have been made operational in private industry and are available for sale. It could be considered mature once a commercially successful technology has been in operation for 10 years or longer. It is considered a historical technology when it is no longer being sold in the U.S. When a technology is emerging, preliminary information is collected. When a technology is commercially successful, it is placed on the active tracking list and additional data are collected, which are used to analyze benefits from program-sponsored R&D. Mature and historical technologies do not need to be tracked.

How technology commercialization tracking studies are organized, conducted, and analyzed: To determine the impacts of research and other activities, a program might not only track commercial progress associated with completed R&D activities but also periodically review and analyze benefits from its technology deployment efforts. Technology commercialization and technology deployment impact information could be combined to provide more complete documentation of the program's impacts. A program contacts vendors and users of sponsored technologies that have been commercialized to collect technical and market data on each commercially successful technology including details on the following: number of units sold, installed, and operating in the United States (including size and location); units decommissioned since the previous year; energy saved; environmental benefits; improvements in quality and productivity; any other impacts such as employment and effects on health and safety; and marketing issues and barriers. This information is used to estimate the number of units that have penetrated the market, conduct engineering analyses to estimate energy savings from the new technologies, and estimate air pollution and carbon emission reductions. The associated reduction of air pollutants is based on the type of fuel saved and the pollutants typically associated with combustion of that fuel using assumed average emission factors. Data collected to estimate commercialization impacts, when also combined with results from a separate impact evaluation of program deployment efforts, provide the total energy and cost savings attributed to the program's efforts. The cumulative energy cost savings minus the cumulative program costs and industry implementation costs provide an estimate of the direct net economic benefit of the program.

Limitations: Several factors make the tracking task challenging. Personnel turnover at developing organizations as well as at user companies makes it difficult to identify commercial applications. Small companies that develop a successful technology may be bought by larger firms or may assign the technology rights to a third party. As time goes on, the technologies may be incorporated into new products, applied in new industries, or even replaced by newer technologies that are derivative of the developed technology. Because the trail may be lost and some program-sponsored technologies that reach market may not be identified, documented program benefits may be thought to be conservative estimates. Furthermore, estimates of program benefits do not include either derivative effects resulting from other new technologies that spin off of program-sponsored technologies, or the secondary benefits of the energy and cost savings accrued in the basic manufacturing industries downstream of the new technologies. Therefore, actual benefits could be higher than the numbers reported. One challenge in properly applying a technology commercial tracking method has to do with separating the effects of successful R&D from the technology deployment effects. Good R&D programs include both R&D and deployment aspects. It will be necessary to separate the R&D commercialization and the deployment effects to avoid double counting when estimating the cumulative net benefits of the program.

Uses:

- To identify which projects funded by the program were commercialized and to what extent.
- To provide documented evidence of the impact of program-sponsored technology development and deployment efforts.
- To estimate the cumulative net benefits of the program.

Examples: Pacific Northwest National Laboratory (PNNL) has tracked and classified commercialized energy-efficiency technologies for DOE's Industrial Technologies Program (ITP). The ITP has tracked progress of their sponsored technologies for more than 20 years. The first example illustrates the first two uses of the method by showing the tracking of two individual technologies funded by the ITP. The second example illustrates the third use by showing the calculation of cumulative net benefits of the ITP as of 2004.

<u>Example 1: Tracking information for two ITP-sponsored technologies</u>
Two samples of project tracking information are contained in the two figures shown below, which are taken from the current version of the tracking document available on the ITP web site. The first, Figure 2-15, shows tracking information for improved composite tubes for Kraft recovery boilers. The second, Figure 2-16, shows tracking information for a steel reheating furnace improved with a new Oxy-Fuel Burner.

<u>Example 2: Calculating net benefits of the ITP</u>
Figure 2-17 shows cumulative net benefits of the ITP estimated as cumulative cost savings minus cumulative program and industry implementation costs from 1976 through 2004. This measure takes into account the cumulative energy savings associated with successfully commercialized ITP-sponsored technology research, including the two projects illustrated in Figures 2-15 and 2-16, along with savings associated with ITP's Technology Delivery Subprogram during the period covered. The costs of industrial energy saved are the average fuel price that would have been paid to purchase energy multiplied by annual savings. The nominal prices (in dollars per million Btu) for various fuels are reported in the Energy Information Administration's *Annual Energy Review*; and these prices are appropriately adjusted by applying the BLS producer price index for Number 2 fuel oil, natural gas, coal, and electricity, normalized to a base year (in this example, the base year is 2000). To obtain the savings in dollars, the prices are multiplied by the respective quantities of each type of industrial fuel saved by ITP-funded technologies that have been commercialized and tracked.

The program costs of the ITP include the cumulative Federal funding spent on the program and the costs of industry of implementing the technologies. Program funds are R&D dollars spent by ITP each year since the program began, adjusted for inflation. As of FY2004, the cumulative ITP spending since 1976 more than $2 billion. Because reliable information about the costs of industry installing the new technologies is not available, an assumption was made to account for these costs: Industry is assumed to require a two-year payback period on investments. To account for implementation costs, the first two years of the cumulated energy savings for each technology are ignored because these saving are needed to "recoup" the capital costs of adopting the new technology.

Figure 2-15. Tracking Information for Composite Tubes for Kraft Recovery Boilers

Improved Composite Tubes for Kraft Recovery Boilers

Impacts

New Alloys Improve Performance and Safety

Black liquor recovery boilers are critical components of kraft pulp and paper mills. These boilers burn organic waste to generate steam and electric power for the mill and allow the sodium hydroxide and sodium sulfide used in the pulping process to be recovered. The boilers are constructed with floors and walls of tube panels, and these tubes circulate pressurized water to permit generation of steam. Originally, carbon steel tubes were used for these tube panels, but severe corrosion thinning and occasional tube failure led boiler manufacturers to search for materials that could better survive in the recovery boiler environment.

As a result of this search, new weld overlay and co-extruded tubing alloys were developed and are now being used in United States kraft recovery boilers and foreign installations. These materials are currently produced by Welding Services Inc., Sandvik Steel, and Sumitomo Metals for application in recovery boilers. Boiler manufacturers are using the technology in designing and fabricating new and rebuilt kraft recovery boilers

A series of alloy studies, conducted by Oak Ridge National Laboratory, Pulp and Paper Research Institute of Canada, and the Institute of Pulp and Paper Science and Technology showed that Alloys 825 and 625 are more resistant than 304L stainless steel to cracking. Sandvik Materials Technology produces Sanicro 38 (modified 825) composite tubes for the world's largest manufacturers of black liquor recovery boilers. The boilers have been delivered to plants in the US, Australia, Belgium, Brazil, Canada, China, France, Finland, Sweden, Germany, Spain and Norway.

Benefits

Environmental

The change in operating conditions resulting from the improved materials will reduce gaseous emissions.

Productivity

Improved materials enable the use of black liquor with higher dry solids content, thus increasing the thermal efficiency. The improved materials decrease the number of shutdowns and improve the overall boiler efficiency and productivity.

Safety

In recovery boilers, tube leaks can result in serious explosions if the pressurized liquid contacts the molten salt on the floor and walls of the boiler. The use of improved materials significantly reduces the cracking of the floor and wall tubes, thus reducing the likelihood of a boiler tube leak.

Overview

- Currently produced by Welding Services Inc., Sandvik Steel, and Sumitomo Metals for application in recovery boilers
- Commercialized in 1996 and installed in over 17 kraft recovery boilers in the United States

Energy Savings

(Trillion Btu)

Cumulative through 2003	2003
0.031	0.007

Emissions Reductions

(Thousand Tons, 2003)

Particulates	SO_x	NO_x	Carbon
0.0	0.002	0.001	0.128

Applications

Being used in constructing new and rebuilt kraft recovery boiler floors

Capabilities

The new materials can operate in the aggressive environments that can cause stress corrosion cracking of 304L stainless steel.

Figure 2-16. Tracking Information for a Steel Reheating using Oxy-Fuel Burners

Steel Reheating for Further Processing

Impacts

New Oxy-Fuel Burners Reduce Energy Use While Reducing Emissions and Increasing Productivity

Steel reheating is an energy-intensive process. Historically, "recuperators" have been used to preheat combustion air, thereby conserving energy. Innovations that are more recent include oxygen enrichment and the use of regenerative burners, which provide higher preheat air temperatures than recuperators. These processes increase NO_x emissions with increased air preheat temperature, unless special equipment is used. NO_x is an industrial pollutant whose emissions are being increasingly restricted.

With assistance from a NICE[3] grant, Praxair developed and demonstrated a low NO_x, oxygen-burner retrofit using 100% oxygen. The burners require less fuel to heat steel and promote lower overall heat content in the waste gases. Energy use was reduced by 60% from five to two million Btu per ton of steel processed. Air burners can be retrofitted or new burners can be installed where the fuel and oxygen are injected through separate ports rather than through a single burner. The low NO_x feature of this system is expected to be a general requirement of the steel industry of the future. The Praxair technology provides exceptionally uniform heating of the steel. This results in better rolling-mill performance and allows a reheat furnace to economically operate at higher production rates. Successful implementation of this technology eliminates the need to periodically replace recuperators and install NO_x removal equipment.

Overview

- Burners are available from Praxair, Inc.
- 4 burners retrofitted on No. 6 furnace at ISG/Bethlehem Steel's Burns Harbor Plant

Energy Savings

(Trillion Btu)

Cumulative through 2003	2003
0.847	0.154

Emissions Reductions

(Thousand Tons, 2003)

Particulates	SO_x	NO_x	Carbon
0.0	0.0	0.018	2.44

Benefits

Emissions Reductions

Reduces NO_x emissions and particulates by 60 to 90% per ton of steel.

Productivity

Provides uniform heating of steel, resulting in better mill performance and an increase in productivity of 3%.

Profitability

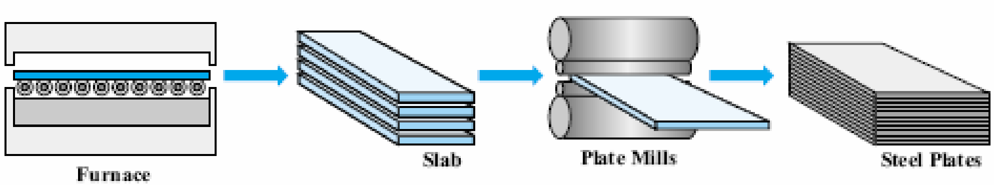
Eliminates the need for recuperators and NO_x removal equipment.

Applications

- Steel reheating furnaces
- Burners can be retrofitted or added to new furnaces

Capabilities

- Reduces NO_x and particulate emissions from steel furnaces.
- Results in energy savings per ton of steel while increasing the quality of the metal.

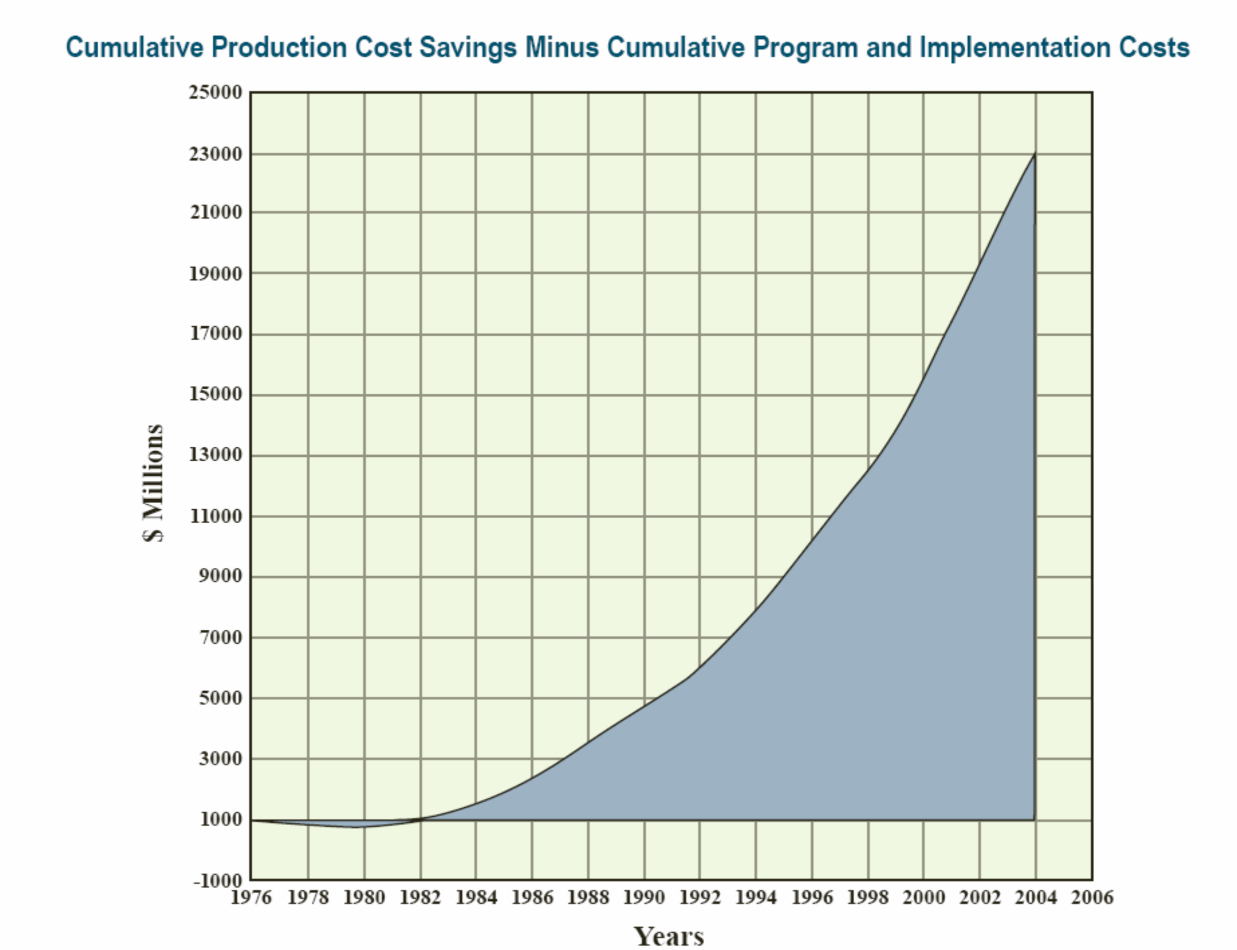


Production of Steel Plates Using Reheat Furnace

The sum of all energy saved times the average energy price yields an estimate of the annual savings for all technologies in a particular year. The net economic benefits equal the accumulation of these energy cost savings over time minus the ITP program costs (appropriations) and the assumed cost of installing the technologies (which is equal to the first two years of savings). Yearly net benefits are then adjusted for inflation using the annual implicit price deflator for GDP, as published by the Bureau of Economic Analysis of the U.S. Department of Commerce, but renormalized to the current year so that all savings are reported in 2004 dollars.

As of 2004, the cumulative value for energy savings of all commercial and historical ITP technologies (both from program R&D and technology delivery efforts) was 4.7 quads, from 1977 thru. 2004. Cumulative net economic benefits associated with the Program is equal to $23 Billion (1977 to 2004), as shown in Figure 2-17.

Figure 2-17. Cumulative Net Economic Benefits, 1976-2004



Source: U.S. Department of Energy, Industrial Technologies Program,, "Impacts: Industrial Technologies Program --Summary of Program Results for CY 2004," February 2006

Note: This figure includes net total value of energy saved by technology developed in ITP research programs plus the energy cost savings from ITP's deployment programs—Industrial Assessment Centers and the Best Practices Program, minus the cost to industry of using the technologies and minus ITP Program costs.

Reference

U.S. Department of Energy, Industrial Technologies Program,, "Impacts: Industrial Technologies Program --Summary of Program Results for CY 2004," February 2006

U.S. Department of Energy, Industrial Technologies Program, Appendix 6: "Methodology for Technology Tracking and Assessment of Benefits," available online at www.eere.energy.gov/industry/about/pdfs/impacts_appendix6.pdf, and current ITP tracking documents, downloadable from http://www.eere.energy.gov/industry/about/brochures.html.

2.11 Benefit-Cost Case Study

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. Make R&D progress, review processes, achieve outputs
3. **Disseminate outputs, achieve interim outcomes**
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- Planning information
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- **Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures**
- Spillover effects
- Comparative standing
- **Overview – was it worth it?**

[Goals, phases, and information provided by this method are highlighted]

Benefit-cost case studies quantify positive and negative effects of a project, a cluster of projects, or a program, and compare benefits against the costs using any of several measures. An essential feature of this method is accounting for "additionality," i.e., benefits and costs with the project, cluster of projects, or program as compared with the benefits and costs without it. Benefit-cost analysis has a long history of use in evaluating government projects. More recently, the method has been extended to evaluate clusters of related projects within a given technology portfolio. For retrospective assessment of EERE projects, the National Research Council (NRC) developed a special benefit-cost matrix framework and procedure. NRC is currently developing a counterpart matrix framework and procedure for prospective assessment of EERE projects. This section first summarizes basic principles of benefit-cost analysis, and then gives examples of (1) a benefit-cost case study of a single project, (2) a benefit-cost case study of a cluster of projects, and (3) an NRC retrospective benefit-cost analysis of an EERE project using the matrix framework.

Definition: The benefit-cost case study method begins with a descriptive treatment of the project, cluster of projects, or program, and adds to it quantification of economic and other benefits and costs to the extent possible. Effects that cannot be quantified are described qualitatively. This method is most often used to evaluate applied research and technology programs with well defined goals that lend themselves to at least partial economic interpretation and analysis, though assessed benefits and costs often extend beyond economic effects. In contrast, the method is generally not used to evaluate basic research programs with pure knowledge goals. A strength of this method is that, when well executed, it provides a detailed, documented accounting of the benefits and costs of a government investment, and expresses the results at least partially in financial terms that allow broad comparisons with the return on other investments. The results of a well-done benefit-cost case study can be replicated, offering strong evidence of impact.

How benefit-cost case studies are organized, conducted, and analyzed: Once an in-depth understanding of the subject is developed, the analyst develops an estimation model and gathers data needed to estimate benefits and costs attributable to the project, cluster of projects, or program in question. Attributed beneficial effects are often modeled as acceleration in the onset of benefits as compared with their timing without the project or program, and/or as an increase in the benefits stream. The analysis takes into account the approximate time of occurrence of effects. All dollar amounts are discounted to a common time basis so they can be combined. Effects not expressed in monetary terms are included in the benefit-cost analysis either qualitatively or quantitatively. Typical economic measures that are used to express overall monetary effects are net present value, annual value, benefit-cost ratio, and internal rate of return or, better, the adjusted internal rate of return.[35] Environmental effects are often expressed in terms of reductions in pollutants. Safety effects may be expressed in terms of life-years saved; the value of avoidance of various illnesses may be expressed using a technique called quality-adjusted life years. When used to evaluate a Federal R&D program, the focus is on social benefits and costs, which includes all program effects identified nationwide. The NRC matrix approach has a prescribed format and procedure, but it essentially follows these same basis principles.

Limitations: Because benefit-cost case studies are typically quite detailed and carefully developed and documented, they often require a relatively large resource and time commitment, limiting the number that most programs can afford to develop and also limiting them to uses that are not time pressured. A case study of a single project may not provide information about a sufficiently large part of a program or portfolio to serve as compelling evidence about the overall performance of the program or portfolio. However, this limitation may be overcome either by performing a sufficient number of individual case studies, such that their total benefits may be shown to exceed total program or portfolio costs, thereby demonstrating positive net benefits for the overall program or portfolio, or by achieving the same goal by performing one or several cluster studies.

Uses:

- To demonstrate the economic effectiveness of a given R&D investment (retrospective analysis).
- To guide R&D investment decisions (prospective analysis).
- To provide information to help program managers make decisions to design or revise their program, re-direct existing R&D funds, or allocate new funds.

[35] For guidance on using these measures of economic performance, see Rosalie T. Ruegg, "Economic Methods," *CRC Handbook of Energy Efficiency*, ed. Kreith and West, pp. 101-124.

Examples: Three examples are given. The first example shows how benefit-cost case study was used to estimate the economic benefits and costs of a government-laboratory project which developed cybernetic building systems. The second example shows a cluster study for a set of projects in composite manufacturing technologies to get at benefits and costs of a portfolio of projects within a given technology area. The third example shows the use of the NRC matrix to assess past EERE energy efficiency programs within a benefit-cost framework. All of the cases take into account "additionality," i.e., the difference in benefits and costs attributed to the government. All of them use the techniques of discounted cash flow analysis to treat economic effects. The NRC matrix example calls out environmental and energy security effects, in addition to economic effects.[36]

<u>Example 1: Benefit-cost case study of a government-laboratory project which developed cybernetic building systems</u>
This economic case study evaluates potential economic impacts of past, ongoing, and planned research of the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) aimed at developing and deploying cybernetic building systems (CBSs) in office buildings. CBS is "a multi-system configuration that is able to communicate information and control functions simultaneously and seamlessly at multiple levels." The CBSs addressed by the study include building systems for energy management, fire and security, fault detection and diagnostics, real-time purchasing of electricity, and the aggregation of building stock for multi-facility operations. Table 2-13 shows the NIST laboratory investment in CBS.

The study describes the key components of the laboratory's research on CBS. It discusses the scope and size of the market for CBS products and services. It presents a strategy for identifying, collecting, and measuring benefits and costs from CBS use in office buildings. The economic impact assessment was carried out in two stages: First, a baseline analysis was performed with all input variables used to calculate the economic measures set at the values assumed most likely. Second, nine input variables were varied to conduct Monte Carlo simulations to assess how changing the value of the variables affected the calculated values of the economic measures.

Study results put the cost savings from using CBS products and services at more than $1.1 billion (1997 dollars) to owners, managers, and occupants of office buildings across the nation, based on a study period extending from 1991 (to include the laboratory's earlier investments in CBS research) through 2015. The study examined BFRL's role as a developer of CBS enabling technologies and as a facilitator in their deployment. It estimated that without BFRL's participation, the commercial introduction of CBS products and services would have been delayed to 2010, but with BFRL's participation, they would become commercially available in 2003. Thus the market penetration curve is shifted forward by NIST participation. The estimated value of not having to forego cost savings predicted to accrue during the period 2003 to 2010 was taken as the return on BFRL's program in CBS. The estimated cost savings attributed to the laboratory's CBS research program is $90.7 million, resulting from its investment cost of approximately $11.5 million. Table 2-14 summarizes calculated savings, costs, and other results.

Table 2-13. BFRL Investment Costs in CBS by FY 1991-2004

[36] Effects other than economic are also often included in other benefit-cost studies. The point is that the NRC matrix calls out these other categories of benefits for systematic treatment.

Fiscal Year 1991 - 1997	BFRL Actual Investment Costs (In Thousands of Dollars)	Fiscal Year 1998 - 2004	BFRL Investment Costs (In Thousands of Dollars)
1991	300	1998	1,390[a]
1992	291	1999	1,610[a]
1993	200	2000	2,000[e]
1994	190	2001	2,500[e]
1995	190	2002	2,500[e]
1996	300	2003	1,000[e]
1997	300	2004	500[e]

a = actual investment costs
e = estimated investment costs

Source: Chapman, 1999.

Example 2: A cluster study to assess benefits and costs of a portfolio of projects in composite manufacturing technologies

A cluster study is a grouping of benefit-cost case studies performed for a selection of projects drawn from a portfolio of projects centered in a common technology with a common broad goal. A cluster study allows conclusions to be drawn about the cluster and about the portfolio from which the cluster is drawn. The objective is to combine the methodological advantages of detailed case study and higher-level portfolio overview. Cluster studies help programs avoid the charge of "cherry picking" because even though stronger projects may be selected for analysis, they must bear total cluster costs and, generally, total portfolio costs; other projects in the portfolio are implicitly assigned zero benefits. Multiple cluster studies may be needed to provide comprehensive coverage of a portfolio consisting of projects with different technologies and goals. Using a common set of measures for multiple cluster studies allows them to be rolled up at the portfolio level.

Table 2-14. Calculation of Savings, Costs, and Additional Measures

Savings and Costs		1997 Dollars ($ amounts in millions)	
Present Value Cost Savings Nationwide: Sum from 1991 to 2015 of present value of cost savings nationwide by year		**Cost Savings Nationwide:**	
	= $1,175.6 million	**$1,175.6**	
Present value Savings (PVS) Attributable to BRFL: Sum from 1991 to 2009 of present value of cost savings nationwide by year		**Savings Attributable to BFRL:**	
	= $90.7 million		
		PVS	**$90.7**
Present Value Investment Costs (PV Costs) to BFRL: Sum from 1991 to 2015 of present value of investment cost to BFRL by year		**PV Costs**	**$11.475**
	= $11.475	**PVNS**	**$79.3**
Present Value Net Savings (PVNS) Attributable to BFRL: Difference between present value savings (PVS) attributable to BFRL and present value of investment costs (PV Costs) to BFRL		**SIR**	**7.9**
		AIRR	**16.2%**
= $90.7 - $11.475	= $79.3 million		
Additional Measures			
SIR of BFRL Contribution: Savings-to-Investment Ratio on BFRL investment			
= $90.7 / $11.475	= 7.9		
AIRR of BFRL Contribution: Adjusted Internal Rate of Return on BFRL investment			
$= (1 – 0.07) * 7.9^{1/25} – 1$	= 0.162		

Source: Chapman, 1999.

Figure 2-18 diagrams a cluster study for a portfolio of composite manufacturing technologies—one of four cluster studies funded by the ATP over the past 10 years. The portfolio of composites manufacturing is composed of 22 projects. A cluster of five projects was selected for analysis. Detailed quantitative benefits were estimated for two projects in the cluster as indicated by the solid lines pointing to "combined cash flow estimates." Possible future benefits from the other three projects are described but not quantified, as indicated by the dashed lines pointing to "combined cash flow estimates of public benefits." The estimated public benefits of the cluster study provide data for calculating performance metrics for the cluster of five projects, as indicated by the downward pointing solid arrow. The larger box to the right represents ATP's investment in the portfolio of 22 composite manufacturing projects used in the calculation of portfolio performance metrics, as indicated by the downward dashed arrow. The smaller box represents ATP's investment in the five cluster projects used in the calculation of cluster performance metrics, as indicated by the downward pointing solid arrow.

ATP has used its cluster studies as evidence to stakeholders that the program is having economic impact. It has used the results internally to assess and compare net benefits of investments in different technologies and sectors of the economy.

<u>Example 3: NRC Benefit-Cost Matrix for Retrospective Analysis of EERE Projects and Programs</u>
Appropriations legislation for the U.S. Department of Energy's energy R&D budget in FY 2000 directed a retrospective evaluation of benefits to the nation from DOE's energy efficiency and fossil energy research programs from 1978 to 2000. Conducted by the National Academies' National Research Council (NRC), the study investigated whether the programs' benefits justified the past expenditure. Study findings were reported in *Energy Research at DOE; Was it Worth it?* (NRC, 2001)

In the effort to take a comprehensive and consistent approach, the NRC appointed a Committee on Retrospective Benefits to develop an evaluation framework using the matrix shown in Table 2-15 for summarizing the benefits of each discrete program with a definable technology objective and outcome. An accompanying "cookbook" gave detailed instructions on how to calculate the benefits in each cell of the matrix. The effect of the program was considered in comparison with the situation without the program, but a default assumption was used that the program accelerated outcomes by five years unless there was strong evidence that an alternative assumption should be used.

The columns of Table 2-15 were used to reflect three levels of uncertainty about benefits and costs, captured with the help of Table 2-16, which focused on two sources of uncertainty: technological uncertainty and uncertainties about economic and policy conditions. The first column of Table 2-15, "realized benefits and costs," is for highly certain benefits and costs, i.e., it is assumed that the technology is developed and the economic policy conditions are favorable for commercialization. The second column, "options benefits and costs," is for recording benefits and costs that are less certain, because though the technologies are developed, the economic and policy conditions are not yet favorable—though they might become favorable at a later time. The third column, "knowledge benefits and costs," is for all other combinations of technology development and economic/policy conditions. The rows were used to reflect three types of benefits: economic benefits to producers and consumers, environmental benefits such as reduced emissions, and security benefits, such as reducing oil imports and improving the reliability of electricity supplies.

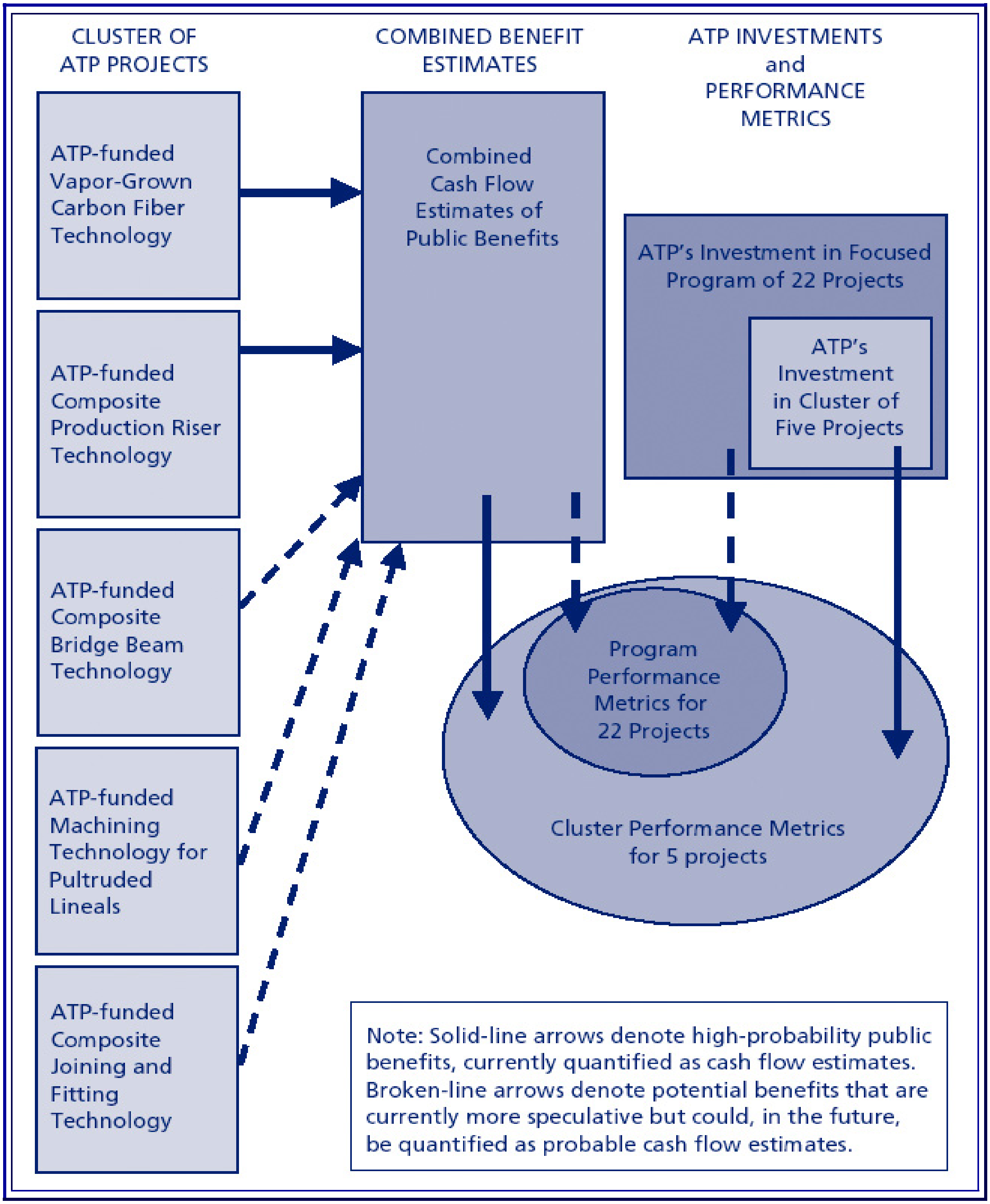
The Committee implemented the retrospective evaluation approach in 39 case studies—22 in fossil energy program and 17 in energy efficiency. The retrospective study concluded that the benefits of federal applied energy R&D overall had exceeded the costs over the period examined, but that within the aggregate were "striking successes" and "expensive failures." It acknowledged that the retrospective study did not reveal the results of future investment decisions.

To illustrate, Table 2-17 shows the NRC benefits matrix for the Advanced Refrigerator-Freezer Compressors Program, with economic benefits far exceeding costs in this case. Economic benefits are estimated at $7 billion and DOE R&D costs at $1.6 million. Environmental benefits are identified as substantial emissions reductions from reductions in energy consumption. Security benefits are identified as improved electric systems reliability. However, neither environmental nor security benefits are quantified.

The Retrospective Benefits Committee recommended that DOE implement the approach, using consistent assumptions across programs, and that it adopt procedures to enhance the transparency of the process.[37] EERE has adopted much of the framework proposed and staff has been working to add to specificity to that framework.

[37] In 2003, Congress asked the NRC to take a direct role in assessing prospective benefits of proposed future investment in the same set of EERE applied energy R&D program."(House Report, 2002, p. 125) The NRC committee is adapting the matrix approach in combination with decisions tree support to assess prospective benefits..

Figure 2-18. Diagram of a Cluster Study



(Source: Pelsoci, 2004)

Table 2-15. NRC Benefit-Cost Framework

Retrospective Evaluation Matrix			
	Realized Benefits and Costs	Options Benefits and Costs	Knowledge Benefits and Costs
Economic Benefits and Costs			
Environmental Benefits and Costs			
Security Benefits and Costs			

Source: NRC Report, 2001.

Table 2-16. NRC "Tool" to be used with the Benefit-Cost Matrix

Accompanying Tool for "Loosely" Characterizing Uncertainty in Retrospective Study			
Technology Development / Economic / Policy Conditions	Technology Developed	Technology Development in Progress	Technology Development Failed
Will be favorable for commercialization	Realized benefits	Knowledge benefits	Knowledge benefits
Might become favorable for commercialization	Options benefits	Knowledge benefits	Knowledge benefits
Will not become favorable for commercialization	Knowledge benefits	Knowledge benefits	Knowledge benefits

Source: NRC Report, 2001.

Table 2-17. NRC Estimated Benefits and Costs Matrix for the Advanced Refrigerator-Freezer Compressor Program

	Realized Benefits/Costs	Options Benefits/Costs	Knowledge Benefits/Costs
Economic Benefits/costs	DOE R&D costs: $1.6 million Substantial benefits: Approx. $7 billion Design modifications to compressor Facilitated efficiency standards Applications software	Minimal: technology has been commercialized and deployed	R&D on system optimization R&D helped develop and define future refrigerator efficiency R&D on energy saving components and features Research findings were applied to air conditioners
Environmental Benefits/Costs	Substantial emissions reductions Reductions in energy consumption	Minimal: Technology has been commercialized and deployed	Benefits could be large as technology is disseminated
Security Benefits/Costs	Improved electric system reliability Minimal benefits, since most of the electric energy saved displaced fossil, nuclear, or hydro, and little oil was displaced	Benefits are relatively small because little oil would be displaced	Successful technology transfer to other nations could substantially increase worldwide energy efficiency and reduce environmental emissions

Source: NRC, Was It Worth It?, 2001, p. 98.

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Robert E. Chapman, *Benefits and Costs of Research: A Case Study of Cybernetic Building Systems*, NISTIR 6303 (Gaithersburg, MD: National Institute of Standards and Technology, March 1999), available on-line at http://fire.nist.gov/bfrlpubs/build99/PDF/b99003.pdf.

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Thomas M. Pelsoci, Composites Manufacturing Technologies: Applications in Automotive, Petroleum, and Civil Infrastructure Industries, NIST GCR 04-863 (Gaithersburg, MD: National Institute of Standards and Technology, June 2004).

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2.12 Econometric Methods

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. **Make R&D progress, review processes, achieve outputs**
3. Disseminate outputs, achieve interim outcomes
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- **Planning information**
- **Indicators of interim progress**
- Analysis of collaborative and other relationships
- Creation and dissemination of knowledge outputs
- **Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures**
- Spillover effects
- Comparative standing
- **Overview – was it worth it?**

[Goals, phases, and information provided by this method are highlighted]

Econometric methods encompass a number of mathematical and statistical techniques that are used to increase the rigor of estimation of economic relationships. Econometric methods are often used to estimate program impacts.

Definition: "Econometric methods" use a variety of statistical and mathematical tools and theoretical models to analyze and measure the strength of functional relationships that underpin a program and to analyze and measure a program's effects on firms, industries, innovation, and the economy. Among the numerous models that have been developed, some have been refined for repeated application, such as the two given here as examples. Because of the rigor offered by econometric methods where there are good models and data, they are often favored when analysts are attempting to show cause-and-effect relationships—a challenging task in evaluation.

How econometric studies are organized, conducted, and analyzed:
Econometric studies usually start with a hypothesized relationship to be tested or a cause-and-effect question to be answered. Examples of evaluation questions that might be answered using econometric methods are the following: Did Program X increase the formation of collaborative research ventures? What was the effect of Federal R&D on private-firm R&D productivity? What are the forecasted national income effects of an R&D program that increases energy efficiency in buildings by 10%? An econometric study proceeds with construction or adoption of a study design and theoretical modeling to guide the approach to be followed in testing the

hypothesized relationship or answering the research question with quantitative rigor. Because econometric methods are highly quantitative, data compilation is an integral part of the model building. Developing a workable model, fitting data to it, exercising the model, and interpreting the results are steps that complete the study. Specialized models and software tools may facilitate structuring analyses and performing computations.

Limitations: Econometric methods may be complex and difficult for the non-specialist to understand and interpret, and, hence, difficult for the specialist to communicate to non-specialist audiences. There may be important effects that can not be captured in a highly quantitative approach. Considerable effort is typically needed to obtain and prepare the necessary data, making these data intensive methods often costly and time consuming to implement. Moreover, the ideal data for implementing a model may simply not be available, causing the analyst to use proxy data which may produce less accurate results. Econometric methods are generally imperfect and variable in how well they capture relationships between R&D investment and changing economic, technological, and social phenomena.

Uses:

- To measure the impact on an organization's productivity of participating in government-funded research.
- To estimate prospective consumer surplus benefits from government-funded technologies using a cost-index approach.
- To estimate retrospective effects of a program-induced change.
- To assess the effectiveness of a public policy.
- To increase the return on a program's investment by improving understanding of underlying relationships and how they may be made more effective.
- To predict an output quantity based on an input quantity.
- To provide defensible evidence of a program's impact.

Examples: The tools of econometrics and statistical analysis are found in many economic studies, including those that feature other methods. For example, the study by Feldman and Kelley, an example given in Section 2.8, "Survey Method," used control groups and statistical and econometric methods to extract more information and greater rigor from survey results. Here we provide two additional examples of econometric methods in the first and second uses listed above, respectively. The first is an econometric analysis of the impacts on research productivity of firms participating in government-funded research consortia. The second is an econometric analysis that estimates consumer benefits from government-funded advances in digital data storage.

<u>Example 1: Using a production function to measure the impact on research productivity of participation in government-funded research consortia</u>

A goal of the Advanced Technology Program (ATP) is to foster collaboration. One way this is done is by offering larger funding amounts for projects proposed by research consortia than for projects proposed by single firms. A research question of interest to the program and its stakeholders, as well as to others concerned with the impacts of R&D consortia, is whether participation in research consortia increases the research productivity of participating firms.

To test whether a statistical relationship between consortia participation and an increase in a firm's research output can be observed empirically, two economists, Mariko Sakakibara of the University of California and Lee Branstetter of Columbia Business School, developed an econometric model for this purpose. The model is a log-linear equation, derived from a knowledge production function:

$$\rho_{it} = \beta_o + \beta_1 r_{it} + \beta_2 C_{it} + \Sigma_d \delta_d D_{id} + \mu_{it}$$

where ρ_{it} = natural log of the number of patents generated by firm *i* in year *t*; r_{it} = the natural log of firm-level R&D spending; C_{it} = the intensity of participation in research consortia, measured as the count of concurrent projects in which firm *i* was involved in year *t*; δ_d = the coefficients on the industry dummy variables (Ds); μ = an error term; and δ terms are industry-level differences in the propensity to patent.[38]

Patent data were used as the indicator of firm research productivity. The analysts used data on Japanese funding of R&D consortia and Japanese firms initially to develop and test the model because there is a longer history of Japanese funding of research consortia offering greater availability of data needed to develop, test, and verify the model.[39] Then, in a follow-on effort, the analysts used panel data (longitudinal data) for firms participating in ATP-funded consortia and for a control group of U.S. non-participating firms to measure the impact on firms participating in ATP-funded consortia.

The analysts took steps to rule out the possibility that the chain of causality might run from firms with high research productivity seeking to participate in ATP research consortia, rather than in the hypothesized direction, i.e., that participation in consortia leads to higher research productivity. They obtained information on total R&D spending, sales, and capital investment of participating and non-participating firms from Standard & Poor's COMPUSTAT database. They obtained information on the total patenting of firms from the REI Patent Database developed and maintained at the Case Western Reserve University Center for the Study of Regional Economic Issues.

Study findings were that "participation in ATP-funded research consortia led to verifiable and measurable increases in research productivity of the participating firms." Findings show a positive association between the participation in research consortia and research productivity of the participating firms at all levels of aggregation. The positive impact of participating in consortia is found to be higher when the average technological proximity of participating firms is high, i.e., when the similarity of patenting portfolios of participating firms is high. Findings

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38 Sakakibara and Branstetter, 2002, p. 6.

39 Developing and testing the model using Japanese patent data allowed more time for ATP patent data to be compiled.

provide less clear-cut evidence concerning which kinds of firms benefit most from participation in research consortia.

Example 2: Using the cost index method for estimating prospective consumer benefits from government-funded digital technologies

Two economists, David Austin and Molly Macauley, both with Resources for the Future, developed a new econometric method, the "Cost Index Method," for estimating potential returns to consumers from new technologies.[40] The approach is to compare "observed price and performance for an innovated product against hypothetical, best available price and performance had the technical advance not occurred."[41] That is, "the cost index indicates how much more expensive an equivalent level of services would have been in the absence of the new technology."[42] Consumer benefits are estimated net of the baseline defined for the best available substitute technology which is modeled dynamically, i.e., the substitute is predicted to improve over time. Benefits to consumers are estimated gross (not net) of R&D costs. The method provides a partial assessment of market spillovers, [43] but not knowledge spillovers, i.e., downstream benefits resulting from the use by others of the publications, patents, and other knowledge disseminated from a project. The method can be applied at the planning stage to assess the potential of proposed R&D investments before making an investment decision, or to project potential benefits for use in evaluation, particularly when a program is too new to have realized actual results.

At the heart of the Cost Index Method is the estimation of changes in quality-adjusted prices of a new technology which permits estimating the relevant area under the demand curve for a new technology without having to estimate the demand curve itself. The method treats innovation as an intermediate good, and treats the services it provides as the final good. It treats demand for the innovation as derived from the demand for final goods. According to the researchers, under competitive conditions in the downstream markets, the cost index will correctly estimate the gain to consumers, and, if downstream markets are not competitive, the cost index will yield a lower bound estimate of consumer gain. Figure 2-19 shows schematically the relationships among key model components.

Austin and Macaulay developed their method in research on space technologies selected for trial under the auspices of NASA's New Millennium Program.[44] In the analysis of space technologies, NASA was both the consumer of the technologies and the producer of the downstream product, and the performance and prices were already fairly well known.

Shortly after the NASA work, the Advanced Technology Program (ATP) engaged Austin and Macauley to adapt and apply their method to estimate potential consumer benefits from two digital

[40] Austin and Macauley drew on earlier work by Stanford University's Timothy Bresnahan, whose focus was retrospective applications, to develop the Cost Index Method with its focus on prospective applications. Bresnahan pioneered the cost-index approach for estimating the consumer surplus from early advances in mainframe computers (Bresnahan, 1986).

[41] Austin and Macauley, 2000, p. 5.

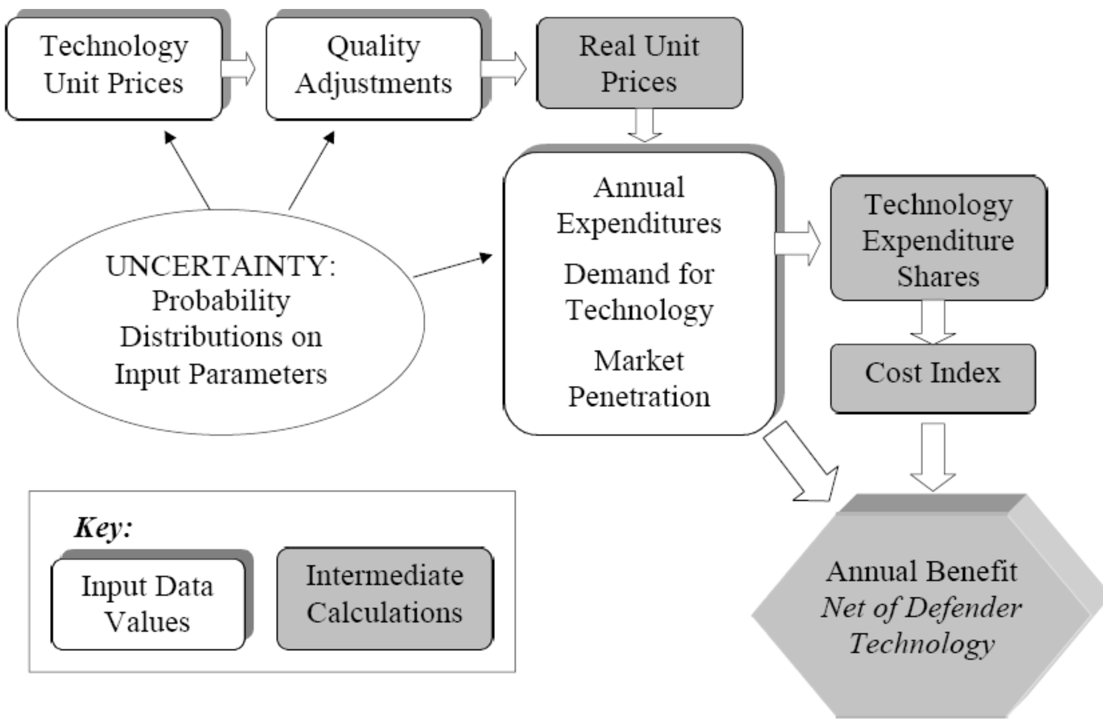
[42] Austin and Macauley, 1998, p. 7.

[43] Consumer surplus is the amount that consumers benefit by being able to purchase a good or service for a price that is less than they would be willing to pay for it. The method does not include producer surplus.

[44] Austin and Macauley, 1998

data storage technologies—optical tape read/write technology and linear scanning of magnetic tape—developed by firms in ATP-funded projects. The ATP technologies were less far along and had more uncertainties than the space technologies. Furthermore, in contrast to the NASA application where the consumers were in-house space scientists, in the ATP application the consumers were downstream buyers of digital storage in the marketplace. To reflect high uncertainty about future outcomes, Austin and Macauley incorporated in the model probability distributions of several parameters, including off-the-shelf nominal prices, quarterly rates of change in these prices, quality differences between performance attributes of the innovation and the defender technologies, market size, adoption rates, personal consumption expenditures, and shadow prices. The ATP analysis reveals the sensitivity of results to these values.

Figure 2-19. Model Inputs, Intermediate Calculations, and Outputs



Both of the ATP technologies were expected to achieve much faster writing and retrieval of digital data than would be possible with defender technologies, and one of the technologies additionally offered a large increase in storage capacity. The study estimated expected benefits to consumers in excess of $1 billion from the optical tape technology, and $2 billion from the linear scanning technology, both projected over a five year period.

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2.13 Historical Tracing Method

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
2. Make R&D progress, review processes, achieve outputs
3. Disseminate outputs, achieve interim outcomes
4. **Commercialization, market acceptance, energy savings, energy security, other outcome s and impacts**

Information Provided by Evaluation Methods:

- Planning information
- Indicators of interim progress
- Analysis of collaborative and other relationships
- **Creation and dissemination of knowledge outputs**
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- Spillover effects
- Comparative standing
- **Overview – was it worth it?**

[Goals, phases, and information provided by this method are highlighted]

The historical tracing method has been successfully used to trace highly successful commercial products back to earlier DOE research. Showing these linkages helps to demonstrate the importance of past research and suggests the potential importance of present research not yet incorporated in commercial products.

Definition: The historical tracing (or "historiographic") method traces chronologically a series of interrelated events either going forward from the research of interest to downstream outcomes or working backward from an outcome along a path that is expected to lead to precursor research. If all likely paths are followed, forward tracing can capture a relatively comprehensive view of a research project's or programs' effects, and, because the path leads from the research, the connection to the research is assured. Backward tracing usually focuses on a single outcome of importance and follows the trail back through those developments that seem to have been critical to reaching the identified outcome—which may or may not link back to the research program of interest.

How historical tracing studies are organized, conducted, and analyzed:
The approach to conducting historical tracing studies has evolved over time. These studies have most often been organized as backward tracing studies to examine key mechanisms, institutions, activities, and processes that seemed to play a key role in an observed innovation. Earlier studies relied mainly on expert opinion solicited by interview to identify and understand key events in the

development of an innovation. Each interview would often identify earlier events, people, and organizations to investigate on the backward tracing path. As computerized citation analysis developed, it was found that citation analysis studies could be helpful in identifying a path of linkages to follow. The result has been the evolution of a hybrid approach to historical tracing studies that combines "detective work," expert opinion solicited by interview, and publication and patent citation analyses. Results have been presented as roadmaps leading to and from research programs to successful innovations.

Limitations: Establishing cause and effect is difficult; antecedents to technological innovations are complex. A given innovation is typically the result of a number of direct and indirect effects, efforts by multiple people and organizations, and the synthesis of advances in knowledge on multiple fronts, often occurring over decades prior to the emergence of the innovation of focus. Hence, historical tracing studies typically require the elapse of considerable time in order for a history to be established. Substantial judgment is required to assess the comparative significance of various research events; significant events may be overlooked or dropped from an investigation. These studies tend to be time consuming and costly.

Uses:

- To show the path by which a particular research program led to useful downstream products and processes.

- To increase understanding of the evolutionary processes of R&D and innovation.

- To suggest that the benefits of research outweigh its costs by comparing a proven-to-be-valuable innovation against the costs of a research program shown to underpin the innovation.

Examples: Two examples are provided of using historical tracing to investigate the role of Federal R&D programs in downstream innovations. The first example is of an early use of the method in Federal R&D evaluation that relies on interviews. The second example is of a later use that brings in citation analysis, in addition to interviews with experts. While the method has not been used extensively, other examples exist.[45]

Example 1: Using historical tracing in DOD's "Project Hindsight"

The earliest example found of historical backward tracing used by a U.S. government research program is "Project Hindsight," conducted by the Department of Defense in the early 1960s. The study traced backwards over 20 years the development of each of 20 major weapons systems supported by DOD in order to identify the key research outputs that contributed to their realization. The study used the approach of interviewing experts. It linked the support of research to a variety of desirable technological outcomes. It examined characteristics of what were identified as critical R&D events to ascertain whether any general principles could be extracted. A major conclusion related to the science-technology conversion process was that the results of research were most

[45] Project Hindsight was followed by Project TRACES later in the 1960s, which examined key events leading to five technological innovations. A follow-on study to TRACES investigated significant events leading to 10 innovations. A study in the mid-1980s investigated research developments that appeared important to advances in cancer research. A historical tracing study performed in the late 1980s assessed the evolution of a set of DARPA projects.

likely to be used when the researcher was intimately aware of the needs of the applications engineer.[46]

Example 2: Using historical tracing to examine the role of NSF's support of engineering in six innovations

The historical tracing method was later used by SRI International in a two-part study to trace the impact of NSF research on the development of a group of selected major technological innovations.[47] The innovations were the internet, magnetic resonance imaging (MRI), reaction injection molding (RIM), computer-aided design applied to electron circuits (CAD/EC), and optical fiber for telecommunications and analog cellular phones.

The study approach combined qualitative and bibliometric techniques to trace developments. It began by forming a technical review panel to help select the innovations, provide background information on selected cases, and review the cases as they were completed. After the innovations were selected, the study identified the technologies that underpinned each of the innovations and which technologies were unique to each innovation. Study analysts performed a search of online databases to identify references that described the development of the unique underlying technologies. Using database searches and conducting interviews and informal discussions with NSF staff, analysts identified the major companies, Federal labs, Federal agencies, universities, and other organizations that played a significant role in the development of these enabling technologies. Analysts then conducted interviews with those identified, asking them about the history of the technologies and NSF's role. A bibliometric citation study was conducted, searching on keywords found to be important in each area of innovation to help identify patents and papers underlying the technologies.

Study findings included the conclusion that in most of the cases government agency support for R&D was important and that in all of the cases there was government support of graduate education for the scientists and engineers who made major contributions to these innovations. NSF's direct research support was found to be a key factor to successful innovation mainly in the case of the CAD/EC innovation. In retrospect, the richness of the qualitative work was noted as being of prime importance in contributing to the quality of the evaluation.[48]

Table 2-18 summaries the influences of the following NSF support modes in each of the technology cases examined: education, direct research support, direct contribution to the knowledge base, direct contribution to the research infrastructure, direct contribution to supporting technology, organizational leadership, and facilitation of interaction and communication.[49]

[46] Sherwin and Isenson, 1967.
[47] David Roessner et al., 1997 and 1998.
[48] Diana Hicks et al., 2002.
[49] David Roessner et al., 1998.

Table 2-18. Summary Assessment OF NSF Support

Internet	High
RIM	Moderate
MRI	Moderate/Low
CAD/EC	High
Fiber Optics	Moderate/Low
Cellphone	Low

Source: David Roessner et al., 1998.

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2.14 Spillover Analysis Using a Combination of Methods

Program Manager Goals:

- **Improve Program**
- **Communicate why the program is worth doing**

Four Phases of Program Performance Cycle:

1. **Design/revise, plan, select, budget**
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Information Provided by Evaluation Methods:

- Planning information
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- Analysis of collaborative and other relationships
- **Creation and dissemination of knowledge outputs**
- Energy savings, economic, environmental, energy security, option and other benefits, and benefit-cost measures
- **Spillover effects**
- Comparative standing
- **Overview – was it worth it?**

[Goals, phases, and information needs relevant to this method are highlighted]

Spillover analysis can be used to measure the surplus benefits to producers who use new and improved technologies, the surplus benefits to consumers who buy goods and services incorporating the new and improved technologies, the benefits to those in other industries who are able to use the knowledge from the research without having paid for it, and the benefits realized by those whose existing goods and services are increased in value due to complementarities of the new and improved technologies. Spillover analysis reveals to a fuller extent the value to society of research and thereby is important to avoiding underinvestment in research.

Definition: A spillover (also known broadly in economics as an "externality") is an effect that results when an activity undertaken by one or more parties affects another party or parties external to the decision to undertake the activity. These effects may be positive or negative; they may be economic or non-economic. For example, toxic emissions released as a by-product of an industrial process is a negative environmental externality or spillover, while reduced risk of contracting an infectious disease because others receive a vaccine is a positive health externality or spillover. An activity giving rise to negative externalities or spillovers will be oversupplied in competitive markets and an activity giving rise to positive externalities or spillovers will be undersupplied. It has been demonstrated by a large body of evaluation studies that R&D activities generate positive "research spillovers."

How research spillovers arise: Figure 2-20 developed by Adam Jaffe, illustrates how R&D by a firm ("Firm 1") can yield positive spillovers. The firm uses its new knowledge from research to produce better and/or lower cost products. The innovating firm profits and its consumers benefit by receiving more for their money or by paying less. Knowledge gets into the hands of other firms—through its intended release in papers and patents, but also in unintended ways such as by reverse engineering and worker mobility. Some of these other firms use the knowledge gained from Firm 1's research without compensation to improve their own products competing with those of Firm 1, thereby capturing some of the profit from Firm 1's innovation and driving the price down further for consumers. Some use the knowledge gained to innovate in other product markets, realizing profit from Firm 1's research and benefiting their own customer base. Spillovers result from direct commercialization by the innovator, from knowledge captured by others,[50] and, in this example, from a combination of both. Social benefits are the sum of the gains to all producers and consumers, which in the diagram is much larger—due to market and knowledge spillovers—than the gains realized by the firm who performed the research. For this reason, spillovers are often discussed in terms of social versus private returns.

Figure 2-20. Illustration of how R&D Market Spillovers, Knowledge Spillovers, and Their Interactions Create Spillovers that Widen the Gap between Private Returns and Social Returns
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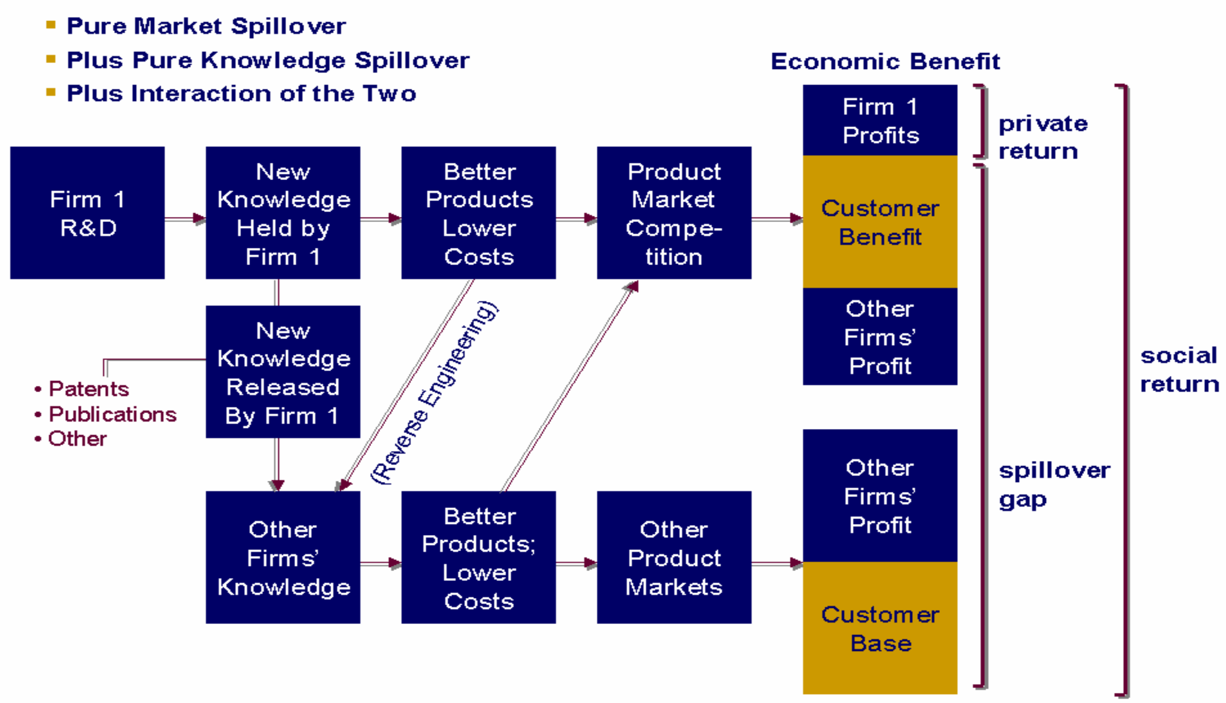

Source: Adam Jaffe, 2003.

Types of research spillovers:[51] Research produces knowledge, and knowledge is difficult to keep from others. Benefits to others that arise due to the uncompensated acquisition and use of an innovator's knowledge are "***knowledge spillovers***." Research also produces innovations reflected

[50] It should be noted that commercialization ultimately is needed for the creation of economic value from knowledge spillovers.
[51] The classification given is after Jaffe, 1996.

in new and better goods and services. Benefits that accrue to customers in the marketplace by an innovator's sale of goods and services that are lower priced, higher quality, or with new and improved features for a price that does not fully compensate the improvements are "***market spillovers.***" A third type of research spillover, likely less common than the first two, are "***network spillovers***," which arise when research and market activities generate benefits to third parties by providing interrelated, complementary, or interdependent technologies, or by creating a critical mass. For example, developing a new software application for a computer operating system may increase the popularity of the operating system, thereby increasing the value of software written for it by other vendors. As additional examples, the value of services provided by website hosts may be increased by implementation of a more powerful search engine, and the value to an individual of having a cell phone may increase in response to an innovation that causes more people to become cell phone users.

Significance of spillovers to public policy: The idea, supported by evidence, that R&D—particularly certain types of R&D under certain conditions—yields large positive spillover effects is one of the rationales for public funding of R&D.[52] The rationale is that the private sector tends to invest less in research than is optimal from the standpoint of society because their investment decisions are based only on the benefits they directly capture, rather than on the total gain by society.

Public vs. private perspectives on spillovers: From the perspective of an innovating firm, knowledge spillovers are generally viewed negatively. Innovating firms seek defensible property rights, trade-secret strategies, reducing worker turnover, and other strategies designed to preserve incentives to pursue commercialization in the face of difficulty in capturing (or "appropriating") the returns from their research. Other firms who are the recipients of knowledge spillovers will see the beneficial aspects. Likewise, a public R&D program views research spillovers as positive. While businesses seek to maximize private returns, government R&D programs seek to maximize social returns (or returns to the nation as a whole). By choosing projects for which research spillovers are large and which are likely to be under funded by the private sector acting alone, a government R&D program can have large, broad impact.[53]

Measuring spillovers: Past evaluation studies have tended to focus either on measuring market spillovers or knowledge spillovers, but not to combine estimation of both knowledge and market spillovers. More has been done in measuring market spillovers, following the lead and general approach of Mansfield.[54] In Section 2-12, an example was given of a cost index method developed

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[52] In addition to spillovers, other rationales for government intervention to foster more R&D, accelerate R&D, and affect the composition of R&D include higher than average levels of risk for some types of research arising from greater technical complexity and difficulty, longer time to market during which uncertain competition with defender technologies may occur, and/or larger resource requirements than most private firms are willing to bear; difficulty in obtaining funding in capital markets for early stage research; and coordination problems among researchers. As explained by Greg Tassey, 2005, in his focus on underinvestment as it relates to the optimal composition of R&D, defining an optimum rate of investment in elements of industrial technologies which have a quasi-public good character is complex and challenging for R&D policy.

[53] A point that should not be lost sight of is that the principle of "additionality" applies in the analysis of spillover effects just as it does in all evaluations of government program impact. That is, we will need to ask not only to what extent did a government research program yield spillover benefits, but how much of it would not have happened without the government program.

[54] Mansfield, 1977.

and implemented by Austin and Macauley for estimating market spillovers to consumers under certain conditions that avoids the requirement for some of the market data that is required to use the Mansfield approach.[55] More recently, Deng has developed and implemented a method of quantifying the "R&D-equivalent" economic value of knowledge spillovers embodied in patent citations at the firm level, building on work by Jaffe and Lerner and other.[56, 57] There are also possibilities for broadening Mansfield's approach to combine market and knowledge spillover assessment within a single benefit-cost framework to obtain more comprehensive results at the project or program case-study level.[58]

Limitations of measuring spillovers: Measuring spillovers is complex and challenging. Research projects produce outputs which interact uniquely with outputs of other projects, technologies, people, and organizations over their life cycles. Detailed, disaggregated analysis is usually required to ferret out diverse effects of specific innovations over time. Some forms of knowledge spillovers leave few tracks. It is difficult to separate out the various sources and quantities of knowledge used by others in their activities and difficult to attribute outcomes to a particular knowledge source or to apportion outcomes among multiple sources. It is likely impossible to identify and trace all aspects of knowledge flows in all their manifestations; hence, at best an incomplete picture can be obtained. Measuring market spillovers is also challenging because it generally requires considerable information about market demand, supply, and defender technologies, which often is difficult to obtain. Data collection problems also tend to arise when there are long time periods to be researched. Further, because past evaluation studies have tended not to combine estimation of both knowledge and market spillovers, there is absent a rich background of experience and reference work from which to draw comprehensive spillover measurement.

Uses:

- To show the societal impacts of an R&D project or program, much of which may lie outside the scope of direct private returns on investment.
- To demonstrate the importance of public support for R&D and to help make the case for it.
- To provide more defensive evidence of a program's broader impact.

Examples: As was demonstrated in previous sections, there are many examples of evaluation studies that have focused on some aspect of spillovers. Rather than repeat the examples, they are referenced here, along with the approach by Deng, for the convenience of the reader.

An example of market spillover estimation—with the focus on gains to consumers—is given for the Cost-Index Method illustrated in Section 2.13, "Econometric Methods." There, consumers are shown to benefit from research funded jointly by a government R&D program and several innovating companies.

[55] Austin and Macauley, 1998.
[56] Deng, 2005.
[57] Jaffe and Lerner, 2001.
[58] Mansfield, 1996.

Section 2.2, "Bibliometric Method—Counts and Citation Analysis," Example 2, shows how knowledge spillovers can be suggested by citation analysis. And, although the examples of Section 2.5, "Network Analysis," do not explicitly discuss knowledge spillovers, the network diagrams of researcher relationships suggest the flow of knowledge and the likely generation of knowledge spillovers, albeit within the researcher community.

The examples of Sections 2.10, 2.11, and 2.12 used relatively broad measures of benefits that to some extent incorporated spillovers, but did not separately identify them. None of these examples, however, successfully combined estimation of multiple types of spillovers. None of them attempted other than partial estimation of spillovers; none attempted to estimate the downstream value of knowledge spillovers. These are examples that remain to be developed.

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