Conference on
Estimating the Benefits of Government-Sponsored Energy R&D[1]
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SUMMARY OF DISCUSSION IN WORKSHOP C: KNOWLEDGE VALUE[2]

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The primary task of Workshop C was to identify methodologies to assess knowledge benefits both prospectively and retrospectively. In a prospective context, the goal of basic research programs is to produce knowledge. In a retrospective context, basic research leads to results that have commercial value and to economic, environmental, energy security or other benefits. Discussion in Workshop C also touched on the relationship between knowledge and technology programs.

The task of the National Research Council (NRC) study was retrospective analysis of the benefits of technology development programs. From this perspective, knowledge benefits are "economic, environmental, or security net benefits that flow from technology for which R&D has not been completed or that will not be completed." The workshop on knowledge value allowed a group of experts to address knowledge value in more depth, and to consider the perspective of basic research, rather than technology, programs

Summary of Commonly Held Views Within the Knowledge Benefits Workshop

Workshop C handled the key questions in depth but did not address all of questions initially proposed. There appeared to be some agreement within the group on several ideas and suggestions. However, the open questions and differences in opinion on the scope and use of a DOE framework for consistent assessment of knowledge benefits of R&D suggest that Workshop C's ideas will serve as information for further discussion among DOE management and perhaps members of the 2000 NRC study.

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[2] This document is believed to be a reasonably accurate summary of discussions in Workshop C of the conference on "Estimating the Benefits of Government-Sponsored Energy R&D;" but the accuracy is not guaranteed by the workshop rapporteur, Oak Ridge National Laboratory, UT-Battelle LLC, Sandia National Laboratories, Lockheed Martin Corporation, or the U.S. Department of Energy. Furthermore, the opinions expressed by those at the conference are their own and therefore nothing in the reporting of the discussions in Workshop C or of the conference proceedings should be construed as government policy.

[3] Sandia National Laboratories is managed by Lockheed Martin Corporation for the U.S. Department of Energy.

Commonly held views among many of the participants from Workshop C were that:

- "Knowledge" is not in the right place in the NRC matrix, according to many participants in the workshop. They suggested both that DOE-generated "knowledge" should be a new row, and that it should be a consideration in each of the three other areas of benefit. Many participants considered it essential for explaining the benefits of science programs, and therefore, necessary if DOE desires a single, seamless process combining science and technology programs.

- Estimating the benefits of DOE "knowledge" requires detail on what those benefits are. "Knowledge-based Capacity" is a possible name for the row that represents all aspects of knowledge benefits. This detail is included in a sub-framework that assesses several benefits of "knowledge" against four criteria suggested by COSEPUP (the Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine) and the Office of Management and Budget (OMB). See Figure 1.

    - The benefits of knowledge can be summarized as knowledge-based capacity which includes: new ideas, new research tools, enhanced human capital, stronger communities of practice, and transitions and opportunities for transition to applications.

    - The criteria against which knowledge-based capacity can be assessed are quality, relevance or strategic fit, performance, and international R&D leadership. Performance could be interpreted as outcomes or "benefits", or more broadly.

- Technology programs would not feature "knowledge-based capacity" prospectively in discussion of what to fund, but they do need a way to prospectively view and justify funding core competence and capacity. More often, they might evaluate knowledge-based capacity benefits retrospectively.

- Science and the applied research programs can use the proposed sub-framework prospectively or retrospectively.

- Links between the rest of the framework (the top nine cells of the remaining Conference draft matrix, following the removal of the knowledge column) and the proposed bottom knowledge row are crucial.

    - Knowledge populates all the cells. Thus it could be visualized as a third dimension in the matrix or as a thin fourth column in the first three rows. In other words, the participants did not reject the NRC notion that the technology programs produce knowledge along the way. Instead, many participants wanted to highlight that knowledge was also a legitimate and important DOE goal in its own right, in other programs.

    - Stakeholders and downstream potential users need to be included in the judgment of strategic fit; that is, in defining links between science and technology and application.

Many workshop participants agreed that knowledge could also remain as a thin column in the upper part of the matrix, that is, an enabling but not primary category for analysis of benefits of technology programs, using the suggested definition and elements of knowledge-based capacity. Knowledge would also be a row showing benefits of basic research, or separate matrices could be used for basic research and technology development programs.

Other areas of discussion were that:

- DOE, OMB and Congress need to make explicit how they intend to use the information on benefits. Prospective and retrospective assessments have different needs and uses, yet the criteria need to be reconciled.

- The group did not have time to address other questions of options, baseline, and attribution to government activities in depth. However there was agreement among many that: R&D does provide options; the role of the government in fundamental science is growing as industry moves away from longer term research; and R&D evaluators do not talk in terms of a baseline for knowledge, although everyone distinguishes between incremental and breakthrough accomplishments which implies different baselines.

Critique of the Proposed Framework for Defining the Benefits of R&D Programs, and its Use for GPRA and R&D Planning and Evaluation

The focus of the initial session was to critique the proposed framework for defining the benefits of R&D programs, and its use for GPRA and R&D planning and evaluation. Is the framework clear and consistent on how "knowledge" fits into it? If not, what clarification is needed or how should it be changed? Many workshop participants felt strongly that the framework did not adequately capture the benefits of knowledge creation or knowledge contributions to technology programs and to the three areas of benefits -- the economy, the environment, and energy security. After considerable discussion throughout the two days, many in the group agreed that knowledge and capabilities should be added as a row, that is, as an area of benefit. Knowledge also needs to be considered at least a retrospective benefit in the other three rows.

The following summarizes other concerns raised by many of the workshop participants about the proposed framework.

The proposed framework and retrospective benefits assessment are related to the reporting of outcomes, required by the Government Performance and Results Act (GPRA). The more recent President's Management Agenda and R&D Investment Criteria are prospective. The framework is also not sufficiently broad to cover the recommendations for the basic research response to GPRA made by COSEPUP. These recommended measures of success are Quality, Relevance and International Leadership. Draft R&D investment criteria for basic research that have been proposed by OMB use these criteria as well, but include International Leadership under Quality and add a criterion of performance or results. One OMB staff present suggested that performance also included good management, thus was not restricted to benefits assessment. It is important to more clearly define and rationalize these values and

requirements to avoid conflicting incentives and to avoid unnecessary expenditure of resources.

For many workshop participants, some of the specifics about filling in the matrix are likely to be harmful for basic research. For example, the proposed five-year time frame for benefits will truncate the R&D process and push researchers away from more long term, risky research. There was also concern expressed about the description of failures. The group was reminded that no one saw John Nash's (A Beautiful Mind) Nobel Prize-winning work as relevant until 25 years after he published it.

Concern was expressed about using only the "most likely" scenario. A better approach may be to have several scenarios to use in planning and assessment.

The matrix as proposed does not provide sufficient information for planning, particularly at the portfolio level. It seems to emphasize the trees and not the forest. The matrix is geared toward downstream impact. It does not recognize the whole R&D process/system of innovation, and the rich role of government R&D in that process. The issue is how to manage the uncertainty of basic and applied research; thus the process, such as use of peer review, becomes important. The matrix does not include important portfolio questions of timing, risk, and who is impacted. The matrix has no critical needs-information such as the U.S. competitive position in an area.

One purpose of assessment is to make a case before Congress and to communicate with the outside world. But it is not just a budget game. There is also the need for assessment to provide information about the organization, management, and incentives. Managers need prospective information to make investment decisions, particularly in the case of long term, lumpy research. Managers need to understand their programs in terms of the total logic, including knowledge gaps for applied research. To be a learning organization we must go beyond the current proposed framework. OMB also looks more broadly than impacts and wants programs to present the big picture, especially for knowledge benefits. Perhaps the "Planning Process" would be better than a "Prospective benefits" column.

Finally, the relationship between retrospective and prospective measures and assessment is critical. How does one link them?

"Knowledge" Has Many Meanings

In his presentation to the group, Irwin Feller suggested that science is a cumulative, cascading, process -- the generation and transmission of knowledge. "Knowledge" has multiple meanings.

MacHlup, in his book *Knowledge, Its Creation, Distribution and Economic Significance* lists 33 different questions that relate to different kinds of knowledge such as knowing how and knowing what. The fact that knowledge has multiple meanings means that it can be measured in multiple ways and measures may have different meanings.

Knowledge As a Row Instead of a Column

After much discussion, many of the participants in the workshop held the view that knowledge-based capacity should not be treated as only one of the range of benefits in the rows of the NRC matrix, but should also be treated as an area of benefit in its own right (a row). The DOE Office of Science and other fundamental and applied research programs in DOE have as their goal to advance knowledge, knowledge that is foundational to DOE missions and national needs. Knowledge is a DOE goal just as economic competitiveness, environmental quality, and national security, including energy security, are. Furthermore the technology programs represented in the group wanted those funding their programs to recognize the value of building and maintaining capabilities and they saw the knowledge benefits as a way to measure benefits that are not in the NRC matrix such as student competitions and technology diffusion efforts. Much of the group also saw a “knowledge row" as responding to OMB and GAO requests for providing key information related to investment criteria, planning, and performance reporting. More detail on this discussion follows.

If knowledge is a column, many participants in the workshop would not know what to do with it. Many conference participants wanted to tie knowledge back to the expected payoffs that link it to benefits. Knowledge is also an area of benefit. Advances in knowledge underpin all advances in many aspects of our quality of life. Part of this area of benefit is the development of the capabilities of the research community.

Members of the group turned to the OMB budget examiners present to explain what OMB wants to know. According to them, OMB wants to know if R&D programs make the progress they expected, what happened that the program didn’t expect, and why it is important.

Many voiced the perspective that we should not split out basic and applied research and technology programs -- that we would lose more than we gain. Part of this is perception. Almost all voiced the idea that how the DOE visualizes R&D benefits is important. The visualization of R&D benefits, as stakeholders see it, gets transferred into the system of measurement and management.

At times in the discussion, a few participants expressed the view that two separate frameworks should be used, with knowledge as a column for the applied research programs, and as a row for the science programs. The concerns expressed were that the more the NRC benefits matrix was changed to apply to pure research, the trickier it was, and that it might be better to use a different matrix for technology programs than for science programs. The argument is that if we try to integrate the evaluation of the science and technology programs we create a framework that does not work well for either of them. If we accept their fundamental differences, we could create two frameworks, each optimized for the types of decisions and assessments that need to be made for the two different types of offices. This reasoning was that:

- The energy resource offices would probably not consider the generation of knowledge as part of their core mission and would probably not find it useful to have knowledge as a row in the matrix.

- Discussions about viewing knowledge as a row talked about evaluating the quality of research management. Although this is an appropriate measure of the

performance of a program, some conferees felt that it was not a measure of the benefit of the R&D program.

The concept of implementing two separate frameworks would require further discussion, however, because the group did not discuss what to do if the energy resources offices and science offices R&D benefits could not be viewed together. Workshop participants did not define knowledge or what would be measured if it remained a column for the technology programs.

Knowledge Permeates All the Framework – the Third Dimension

The group grappled with how to convey in the framework and in benefit-assessments the fact that knowledge permeates all the cells of the matrix, that is, it is a third dimension. The government funds science for two reasons, knowledge creation and knowledge as foundation for application. Depending on the reason, there are different views of what is an outcome. Knowledge can be an outcome or an enabler. Placement will depend on the time scale for benefits, the level of uncertainty, and the concrete nature vs. the breadth of the research. Knowledge creation is an outcome for those programs that have advancing knowledge as a specific goal of current program activities.

Much of the knowledge sought under DOE programs is focused on solving problems related to the other three rows. Knowledge is a contributor to an outcome for technology programs as well as a part of planning and analysis for all R&D programs. The example was given of basic research on mid-efficiency furnaces that resulted in a vent design that saved a great deal of energy and money.

Identifying knowledge in a separate column does not display the dependencies well. Parry Norling pointed out to the group that industry sees knowledge as a third dimension of the matrix, underlying all its R&D activities. There is valuation of knowledge at the time of sale and mergers, and many donate IP (intellectual property) to universities and value that carefully as a credit on their books. But the group did not come up with suggestions on how to include knowledge as a third dimension, other than one proposal to explore displaying knowledge as a diagonal on the matrix.

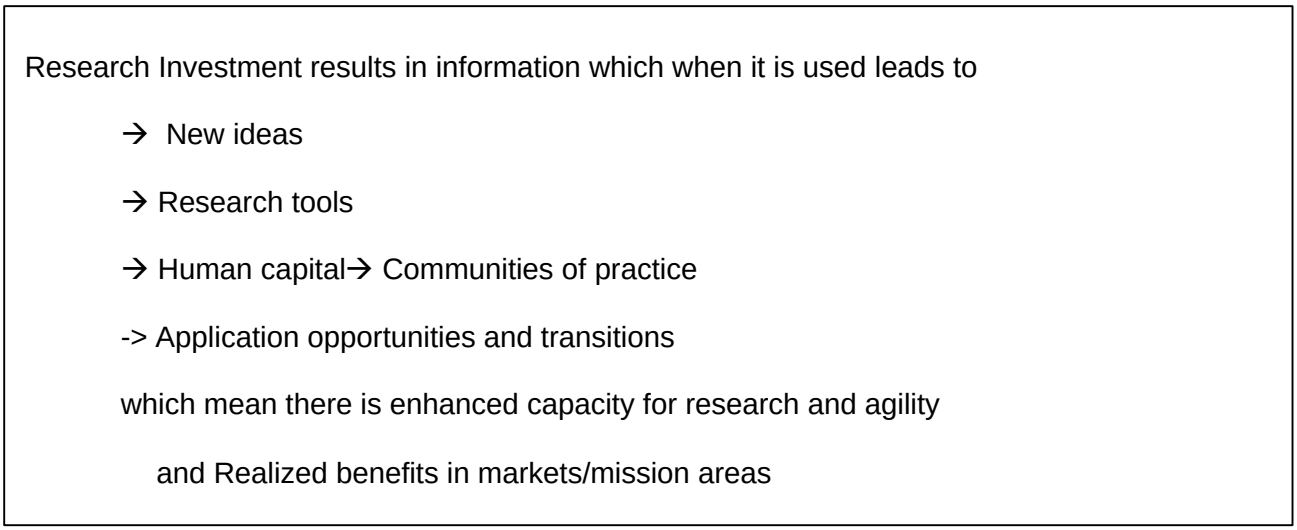
There was also concern that double-counting would have to be addressed. Benefits should be additive. Some will be embedded in products or mission needs, but other knowledge advances are more generic and will be appropriately described in the knowledge row.

The Benefits of Knowledge – A Proposed Sub-Framework

In answering the question “What are the benefits of knowledge and how do (or don't) they fit into the framework”, many in the group wanted to adopt a sub-framework for the assessment of knowledge benefits, where knowledge benefits were broadly defined.

The outputs of research are more than "simple knowledge." Other outputs are educating and training people (referred to as human capital), and networks, knowledge infrastructure and capacity. These allow a rapid response to changes in circumstances and the ability to handle tougher problems. The group was pleased to have Dave

Roessner organize its thoughts by describing a generic logic model for research investment, that is, a description of the outputs and outcomes or benefits of research (refer to figure below). This model was developed for the BES "research value mapping" project in 1994. Workshop participants modified the wording slightly as they discussed these ideas.



This definition of knowledge benefits captures the three major categories of outcomes used by the NSF: People, Tools, and Ideas. Many workshop participants thought that it articulated the process well. It is the way industry now views the R&D process, that is, bringing together R&D information and business opportunities. And it was suggested that with this scheme it is possible to ascertain whether you have a good or bad project. And one could consider the value of a program as all of these things, an in an ecosystem. Depending on what profile of these contributions those who fund R&D want, they will manage to build and maintain activities among the benefits on this list. Not everyone agreed that this scheme helped make resource allocation decisions, however.

The most popular idea among many participants was to add columns with the criteria COSEPUP recommended for GPRA assessment and OMB recommendations for prospective investment criteria, modifying some words slightly. (Precise definitions and overlap were not discussed.)

- Quality of the research
- Relevance of the research, or strategic fit as industry uses the term
- Performance (defined both as results or more broadly)
- International scientific leadership

Together the knowledge row and the proposed sub-matrix respond to OMB and GAO requests with regard to investment criteria and performance reporting. The OMB has indicated that the applied-research investment criteria are moving more toward the basic-research criteria, in part because applied research cannot meet the DOE pilot criteria which are better suited to technology development programs. Joe Wholey of

GAO, speaking to the larger conference, reminded participants that a good response to GPRA includes intermediate outcomes, not just impacts.

The Sub-Framework Tested on a Hypothetical Technology Program

As a test of the knowledge sub-framework the group was challenged to populate the matrix cells with measures for prospective assessment. Representatives of technology programs indicated that they do not consider research activities exclusive of what they are trying to accomplish in a market sense. Thus they would not justify their programs to the Administration or Congress on the basis of knowledge benefit. Intermediate steps are not discussed at this level except as milestones. There may be spin-offs but those will not justify a program either. Knowledge benefits can be documented retrospectively. OMB representatives indicated this was a reasonable approach for programs well down the applied path.

Even if knowledge is not embodied in a successful technology, knowledge can be used in future efforts and save money and time. This would fit under transition activities, for example, the achievement of technical performance such as cost per therm. Some of the technology programs activities fit in the cells of the proposed sub-framework. One office has a student competition to build alternative fuel vehicles. This contributes to human capital. It also enhances communities of practice, as do cooperative research agreements. Other programs fund testing facilities, which fit under research tools and generation of new knowledge. Web site dissemination of technical results fits under transitions as well. This type of program, as well as diffusion programs such as Clean Cities do not fit in the NRC framework, but could fit in the knowledge sub-framework.

The sub-framework helps identify what programs should move from basic to applied, and assists with asking for funding for the new programs. The sub-framework also points out knowledge barriers where programs could ask for assistance from basic programs. And more and more private industry considers that there is justification in funding knowledge capabilities or capacity, so can they keep a steady stream in the R&D pipeline and so they can do R&D fast. The knowledge row is about developing competencies (communities of practice, human capital, transition opportunities). The DOE programs are also concerned about having a critical mass required to make progress. This is not captured well in NRC framework, except perhaps under the option benefit. Some workshop participants from technology programs felt that if capacity/critical mass is seen as valuable and programs were allowed to use as that argument as budget justification, that would be a good outcome of this workshop.

Many in the group shared their perspectives that the technology programs would probably not complete most of the cells in the sub-framework because they would only include significant parts of their programs and what is suggested above are small portions of their work. Thus the sub- framework would probably not be a great help for applied programs, and benefits would not justify the applied programs allocating significant amounts of funding to "fill out" these cells. But if programs had resources, they would "pick up" these knowledge benefits retrospectively.

Testing the Sub-Framework For A Hypothetical Science Program: Prospective Benefits

The experienced R&D evaluators assured the group that filling in this sub-framework retrospectively is easy to do. Thus the challenge to the group was to fill in the cells with prospective questions and measures. Although more thought is needed, the group was able to provide examples of questions or measures for each cell. These examples are shown in Figure 2. Workshop participants observed where there was overlap and items could be combined, but felt it was important and useful to keep them separate. Keeping them separate gives needed emphasis and retains important detail which the group did not want to lose. Many workshop participants saw this sub-framework as being useful and as the intersection of knowledge and prospective benefits.

How Is This Prospective and Retrospective Assessment Going To Be Used?

A senior DOE program planner and evaluator asked what it is that OMB wants to know. Retrospective assessment answers the question “was it worth it”, but can only be answered on completed projects. The programs need to use the criteria as a planning tool, not only as an assessment tool. Programs need to use the criteria to make decisions before the budget gets to OMB. They also need the criteria to differentiate between different kinds of programs. Is it possible that one set of information can do this? Some have thousands of stakeholders, while others have three. Some have lower barriers than others. Some have to be solved in stages. An annual budget snapshot on the current criteria does not reflect those differences, in part because they assess the merits project by project and not at the portfolio level. Projects that are “2s” and terminated may affect the ability to do projects that are “4s”. It is also important to assess a program based on its original purpose and that supporting legislation. It is not appropriate to impose today’s view on something designed and implemented under conditions of uncertainty.

OMB staff responded that the intent of R&D investment criteria is to identify and communicate the data that is useful to OMB. They see it 90 percent as a planning tool. However, they agreed that OMB could do a better job of communicating how these criteria are to be used. Also OMB is redrafting the criteria for applied R&D programs. Retrospective assessments show OMB how well specified and managed programs are, and their relevance and fit. The criteria are used along with other information such as 5-year plans that help put portfolios in perspective and provide understanding of the relationships between projects.

Dave Roessner’s presentation provided a good summary of measures/methods and uses of prospective and retrospective assessment in planning and evaluation, respectively. This is highlighted in Table 1.

To summarize, the focus on prospective or retrospective analysis and decisions leads to different kinds of studies. Usually only prospective analysis leads to developing theories of how to get from inputs to outputs because retrospective-benefit studies typically ignore the “Black box”, the process of managing and doing R&D. Many workshop participants felt that we need to describe what’s in the black box. That forces the use of

management as a decision tool. Black box answers "show you how the manager is valuable." What did managers do that made programs work.

Table 1. Effective Benefit Measures and Methods – Prospective and Retrospective

Program planning & management (Prospective)	**Program evaluation/ justification (Retrospective)**
Criteria for Effective Use of Benefit Measures and Methods	
"Rigorous" - not necessarily quantitative	Credible
Detailed	Defensible
Formal	Intuitive
Quantitative	Transparent
Use of rigorous methods and measures	Evidence of use of "Rigorous" methods & measures
Benefit Measures & Methods That Exhibit Those Criteria	
Inside the black box Inside the organization Process/formative Formal logic models of activity Portfolio anal, balancing risk, long short term, types of impacts (e.g. human capital)	Impacts/inputs Summative Focus on what benefits as opposed to how Case studies/anecdotes
How Benefits Are Realized	
Portfolio analysis Institutional, Organizational, Managerial variable	Peer assessments Client satisfaction Nuggets Additionality/counterfactual Cost, value, impact variables

Concern was expressed that the group hadn't spent much time on what are estimated outcomes. But several pointed out that we have done so. The logic model of knowledge benefits can be used to attribute program activities to knowledge value communities, or communities of practice, for example, and these are the types of outcomes that are important. And peer review with competitive and merit-based selection of research projects assumes prospective review of quality, strategic fit, and to the extent possible, anticipated opportunities for application.

Bibliometric and Industry Measures of Knowledge

Diana Hicks presented the many ways bibliometric techniques can be used in the assessment of research. Bibliometrics could be used prospectively for human capital issues and to trace networks. It is also possible to use bibliometric analysis as an indicator of vitality and where one might need to make investments. For science, by investigating papers that cite other papers, the organization can assess knowledge incoming and outgoing from an organization. By considering the percentage of top-cited papers, one has an indicator of quality and a value distribution across a portfolio. For technology, by considering patents that cite papers and patent portfolios, one can do

network analysis. Tracking people through the patent system would be very valuable, for example to show a need for expertise.

Parry Norling spoke from 30 years experience managing research at Dupont and participation with the Industrial Research Institute's Research on Research Committee. He also spoke of managing the black box. He pointed out that within the non-linear innovation system that includes inputs, processes and outcomes, different stakeholders are interested in different metrics. Norling listed different types of benefits estimating techniques: net present value, rules of thumb, database of assessments, studies by independent analysts, value of IP and orphan patents, and financial analysts' estimates of value. References were provided to several project-scoring mechanisms that might be helpful to DOE.

Norling also addressed the question of what to do about assessing the benefits of basic research and pointed to ideas on radical innovation, knowledge drivers of the future diagram, and strategy tables. A possible benchmark for DOE to use when thinking about risk is a study on the success rate of new products that showed that it took 3000 new ideas to get 300 submitted ideas, and eventually end up with one new commercial success. Thus an organization needs a steady pipeline of R&D.

Parry also showed a portfolio tool, the familiarity matrix, developed by MIT Sloan School. The matrix considers the interdependence between the newness of a technology with the newness of the market to the firm. An organization can use it to manage risk. Pursuing a new technology in a new market is "suicide square," for example. There are many tools, and many estimating techniques. It is important to remember that an order of magnitude estimate is sufficient at first. It is important to verify or rule out assumptions and establish value, and build these reviews into a stage gate process.

To relate back to the matrix, Dupont's approach would fit into the scheme where R&D is a capacity or row, and a third dimension to all R&D activities. Business judgments don't really fit in the matrix, except as management makes decisions on how much risk they want to take.

Role of Government in R&D Benefits

For science programs, attribution of impacts to government programs is particularly difficult because of the long and diffuse path from government activities to the application of knowledge and knowledge capacity generated by those activities. Expert judgment and trends in funding by sector are two indicators of contribution. The industry trend is more dependence on federal basic research. They are doing more outsourcing of basic research and collaboration, being a smart buyer, because they can't do it all and time frames are short in many cases. This trend suggested to the group that in the process of shaping programs, DOE might include a broad group of stakeholders, including industry, financial institutions, and large customer groups.

Figure 1. A Framework For Valuation of Knowledge Benefits

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Measuring Knowledge Benefits

Benefit	Quality	Relevance, Strategic Fit	Performance (Mgmt, Results)	Int'l. Leadership
Knowledge & Ideas				
Tools				
Human Capital				
Communities of Practice				
Transitions & Spin offs				

Figure 2. Example Prospective Questions and Measures for A Basic Research Program