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Setting Priorities and Coordinating Federal R&D Across Fields of Science: A Literature Review

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PREFACE

The National Science Board is presently exploring how the U.S. federal government sets priorities in research and development and whether changes are needed in the decision-making process. Accordingly, the NSB's Committee on Strategic Science and Engineering Policy Issues asked RAND's Science and Technology Policy Institute for a comprehensive review of the relevant literature and experience on R&D priority setting across fields of science. The resulting report surveys the literature to identify descriptions of the budget coordination and priority setting methodologies currently employed by the federal government as well as to examine critiques of currently employed methodologies. The report will be of interest to those with general interest in the realm of science and technology policy and specifically treats issues of priority setting and coordination of the federal R&D portfolio across fields of science.

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SUMMARY

The National Science Board Committee on Strategic Science and Engineering Policy Issues asked RAND to provide a comprehensive review of recent literature and data sources on priority setting and coordination in federal R&D. The full review presents a synthesis of how the literature describes priority setting across fields of science and the issues involved. We have identified gaps in the literature where the process remains unclear and needs explication. We conclude with suggestions for further study. The following summary presents a cursory overview of the main points in the review.

OVERVIEW OF FINDINGS

General Assessment of the Literature

- The literature is weighted toward the prescriptive rather than the descriptive and tends to take a broad view rather than examine operations at the agency level.
- There is a robust literature offering advice to government on how best to set goals and allocate funds, both as a national endeavor and across governmental agencies, falling into three broad categories:
 - a shift to a national-goals approach, tying the priority setting process to national goals;
 - a scientific-goals approach advocating cross-cutting assessments of existing spending in areas of science and realignment of budgets, if needed, to further scientific advancement;
 - fine-tuning of the existing complex, political process.
- A smaller but growing base of procedural publications describes how the process of R&D allocation should be done within an agency or a discipline.
- Only a few reports describe how the process actually takes place within the government and no publications describe the process across fields of science.
- There is only a sparse literature describing efforts at coordination.
- There is a richer discussion of goals and priority-setting within the Executive branch than within Congress. Qualitative discussions of how, or even whether, Congress decides among funding options for different areas of science, different federal R&D programs, or different research project areas are comparatively rare.
- Agencies differ in setting priorities for science based on whether they have a scientific or mission orientation. Most agencies now gather views from various stakeholders combined with strategic planning and goal-setting.

Key Gaps in the Literature

While high-level goal setting is discussed, and the process of peer review and scientific advice is also detailed, there is very little about the vast middle ground where goals-setting meets actual funding obligations. Although reports cite the primary role of the Executive Office of the President in priority setting and coordination, relatively little exists about actual operations such as the role of the NSTC in coordinating federal R&D. The literature cites NSTC as coordinating larger initiatives and crosscuts, although the importance of its decisions versus those of OMB staff is not detailed. Likewise, there is little description of the NSTC role, if any, in determining funding in agency core R&D programs not connected to a larger budget priority or "crosscut."

There is even less detail about the process that takes place within the Executive Branch in the 11 months leading up to the release and explanation of the President's budget. The deliberation within agencies for resources in the period prior to the submission of the proposed budget submission to OMB in September is nowhere in the literature. Likewise, the give-and-take between OMB and the agencies prior to the agencies being "locked out" of the budget in December is not described. There is no mention of how the individual divisions of OMB make decisions, set priorities, or allocate funding. The readjustment of the budget that occurs after the agency "lock out" in December, and when final Presidential priorities are set, is not described in the literature.

Furthermore, there is little description of the ways in which Congressional committees influence the direction and conduct of federal R&D through a number of informal means. Rarer still are documents that elaborate on either the details of these procedures in practice or the degree to which the practice corresponds to formal procedures.

Finally, despite the sizable academic literature on methods for assessing research benefits, there is virtually no discussion of whether or how these have been implemented by the research-sponsoring community.

Best Practices in the Literature

The literature itself offers no clear concept of best practice nor attempts formally to make such an assessment. Doing so would require establishing a metric, a task difficult to perform when agency missions vary so greatly. Yet, the literature might be said to imply a definition of best practice by critiquing present practice, as discussed below. As noted, these critiques generally advocate some selective change rather than offer an integrated design and might be said more to offer views of "ideal" practice than identify best practice.

There are some cases where the U.S. government has adopted some of the recommendations made in different reports but the effectiveness of these changes remains unclear. For example, the White House's creation of a "21st Century Research Fund" addresses some of the criticism that too much development has been lumped together with basic research. Responses to the increased demand for accountability of science and technology have also affected priority setting practice in many R&D agencies. The literature has yet to catch up with these developments, but these changes may be worth further examination.

Government-Wide Coordination and Priority Setting

There is no formally defined process within the federal government to set goals and priorities or make allocation decisions for science. The system is a pluralistic one based in principle on promoting excellence and relevance. Many players with different interests interact to influence the outcomes. Recommendations found in the literature on setting broad goals for federally funded research fall into three broad categories:

- Tying science funding more tightly to national goals;
- A science goals approach with realignment of budgets, if needed, to better meet the needs of scientific advancement; and
- Fine tuning the existing complex, political process.

Suggestions for more detailed models of priority setting in turn may be ascribed to three categories:

- Engaging the scientific community in determining priorities based on scientific needs;
- Benchmarking U.S. capabilities and determining where more emphasis might be placed;
- Seeking scientific and stakeholder input in science to meet agency missions;

Critiques of Currently Employed Methodology

The most frequent criticism addresses a perceived lack of clear methodology for performing priority setting and coordination. Enactment of GPRA has led to changes in agencies' practices, yet a further implicit critique may be found in the actions of the House Science Committee which held hearings in 1996 and 1997 on implementation in the civilian science agencies and announced, in 1997, that this would be a major oversight target. A major argument in the 1995 NRC "Press" report is the need for some form of "comprehensive" and "coherent" coordination of federally-financed research. However, even this recommendation is by no means universally accepted.

Advantages and Disadvantages of Different Methodologies

Best practice in the use of different methodologies suggest that a pluralistic approach is actually the more rational way to make determinations among competing priorities. For example, one argument against a more coherent and integrated federal S&T budget suggests that trade-offs should be made at the agency level between S&T investment and other expenditures; the Press report underestimates the value of the mechanisms already in place, especially the NSTC; and warns against the "overly comprehensive process" proposed by the Press panel.

Other voices argue that the budget process will not provide a method or even an analytic framework for setting the major priorities in the budget because of the diversity of agency goals. The current process recognizes R&D's value and the broad acceptance of its major federal role. Yet, it is too difficult to budget by individual projects. The "level of effort" approach is hard to defend, especially in light of the difficulty of making causal

arguments by tracking direct benefits. Further, under current practice, the fate of entire disciplines sometimes depends upon the funding decisions of individual agencies.

Suggested Approaches to Improving Process

Alternatives to the present processes fall into one of three areas: alternative weightings or other means for deriving priorities from larger national goals; suggestions for alternative mechanisms within existing institutions; and changes in those institutional structures themselves.

Alternative Weightings. In the first area, there are calls to clarify the *raison d'être* for federal R&D support. There are frequent recommendations, for example, to link allocations more directly to specific societal goals. Whatever criteria are chosen, actual processes of selection and allocation should be more explicit. OTA provided an example of one set of criteria for selecting among competing initiatives summarized in Table S-1.

Table S-1. OTA's Suggested Criteria for Selecting Among Competing R&D Initiatives

Scientific Merit	Scientific objective and significance Breadth of interest Potential for new discoveries and understanding Uniqueness
Social Benefits	Contribution to scientific awareness or improvement of the human condition Contribution to international understanding Contribution to national pride and prestige
Programmatic Concerns	Feasibility and readiness Scientific logistics and infrastructure Community commitment and readiness Institutional implications International involvement Cost of proposed initiative

In addition to priorities set by issue area, there are also calls to do so by stage of the research and innovation process or other criteria. Similarly, there are also suggestions to shift the focus of funding in the federal R&D portfolio dramatically toward basic research while others warn that parsing the federal R&D budget by the old definitions of basic and applied research has proved politically ineffective.

Alternative Mechanisms. The second major group of alternatives addresses the mechanisms by which allocations should occur within existing institutions. The concept of best practice might be applied by adapting already-existing models to other federal agencies. Several suggestions have been made for fundamental changes in allocation methods. One would use an options approach where the portfolio is constantly updated, balanced for risk, and takes advantage of increased information availability. Many view the current system as largely successful for the bulk of research needs but suggest that within a pluralistic, multi-agency budgeting approach, some areas require special attention owing to their large potential for spillover effects to other agencies. Several reports point to the paucity of data gathering and the necessity for establishing a database of the federal R&D budget.

Structural Changes. The last category of suggestions addresses the institutions of federal research portfolio management themselves. Several studies advocate a greater role for NSTC, OSTP, and/or OMB in setting portfolio

guidelines. This would constitute a fundamental redrafting of the role of these agencies and the nature of their interactions with the rest of the federal research portfolio management structure. Improved coordination could require

- a comprehensive, comparable data base on R&D budgets;
- a detailed "directory" report to provide information on what agencies are engaged in what kinds of R&D; and
- a report on "R&D in the Budget" each year.

Alongside suggestions for different goals stands the suggestion that a new institutional structure be created, such as a non-governmental National Forum on S&T. Such a body might also define what the essential elements in the federal R&D portfolio must be and suggest ways in which the portfolio's composition may be more readily adapted. Some proposals call for creating a Federal S&T Budget in lieu of the existing post hoc accounting concept and also shifting from a bottom-up to a top-down process. This would force trade-offs at the programmatic level. Yet, at the same time there are voices stating that the current process of trade-offs and political decisionmaking, influenced by advocates of science, actually works fairly well and meets the needs of science for adequate funding.

DEFINING AND DETAILING "R&D" AND "S&T"

Defining R&D

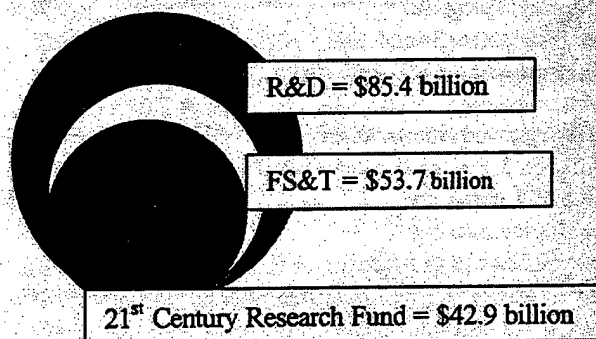
From the outset, a terminology problem confounds attempts to characterize the literature on priority setting and R&D. Although the terms S&T and R&D are often used interchangeably, they have very different meanings in the context of the federal government. Specifically, there is one overarching and official definition of R&D used by all federal agencies¹. Because R&D activities constitute the primary long-term investment of the federal government (education and training is number two), R&D is separately tracked in the federal budget.² Complicating the discussion is the fact that other terms have been introduced, including the "Federal Science and Technology Budget" and the "21st Century Research Fund." Figure S-1 shows the relationship between these three terms.

¹ R&D is a budget category that is defined by the Office of Management and Budget (OMB) in Section 25 of Circular A-11.

² The Department of Defense (DOD) alone among the federal agencies has refined the OMB definition by sub-dividing the Development category. DOD then takes one of these sub-categories, groups it with Basic Research and Applied Research, and collectively refers to these three activities as "S&T" thus designating S&T as a sub-set of R&D.

Figure S-1: The National Academy of Sciences Comparison of 3 "R&D" Budgets

FIGURE 2: FY 2001 R&D, FS&T, and 21st Century Research Fund (in billions)



Source: Research & Development FY20001. Washington, DC: American Association for the Advancement of Science, April 2000.

Defining S&T

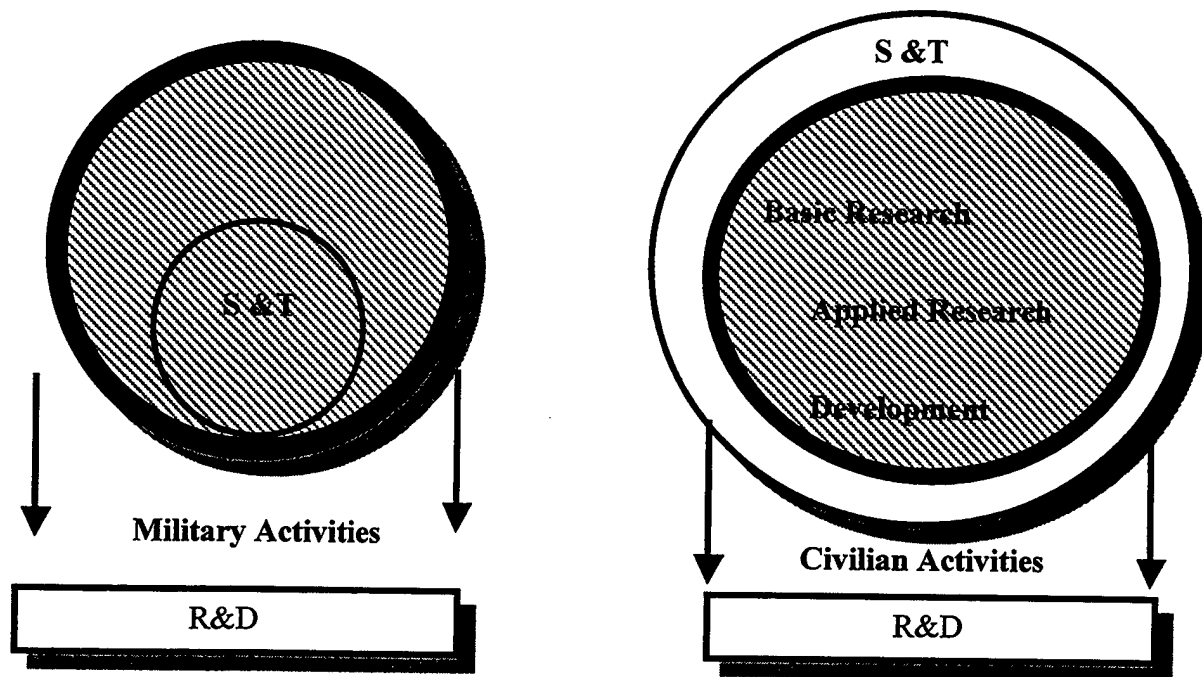
Parallel to the designation of specific federal activities as R&D, there is a simultaneous labeling as to general purpose (i.e., mission) or function activities for S&T. R&D activities are found in every functional category in the federal budget. Of particular interest are the R&D activities in Function 250 – General Science, Space and Technology. All such activities, most especially those of NSF and much of DOE, are officially labeled as S&T activities. Only a part of the activities are categorized as R&D. Consequently, for these agencies, R&D is a sub-set of S&T.

The magnitude of civilian agency S&T activities is hard to determine, because they are not officially labeled S&T. Figure 2 illustrates that specific activities that are widely believed to be R&D are instead S&T activities that fall outside the set of activities officially designated as R&D (e.g., the Manufacturing Extension Program at NIST and the Space Shuttle). Failure to agree on the definition of critical terms and then apply them consistently has defeated and continues to defeat basic communication in the federal R&D community.

Data Issues

The way R&D is defined affects the collection and sharing of government data. Data on the contents of the federal R&D portfolio contain either highly aggregated budget information or disaggregated project descriptions. There is considerable difficulty finding common bases for combining "crosscutting" data collected by different agencies. Moreover, activities not characterized as R&D but which are scientific in nature (i.e., weather data, space travel, mapping) are not included in descriptions of federal R&D activities, leading to some confusion during priority setting and coordination activities.

Figure S-2 Contrasting Defense-Related and Civilian Definitions of S&T



EXECUTIVE BRANCH ORGANIZATIONS

The actual operation and effectiveness of executive branch organizations and processes for coordinating R&D policy, planning, and funding are poorly described in the literature. Most of the material included here is derived from agency procedural documents.

The Executive Office of the President

The Executive Office of the President has four offices or councils that advise the President about priority setting in R&D and S&T. These are:

- **The Office of Science and Technology Policy.** OSTP helps coordinate federal science activities to meet the President's goals. This is primarily done, in the Clinton Administration, through the National Science and Technology Council (NSTC) for which OSTP acts as a secretariat. OSTP, together with the Office of Management and Budget, issues a budget memorandum each year on research and development priorities.
- **President's Council of Advisors on Science and Technology (PCAST).** PCAST's principal task is to assist the NSTC in securing private sector involvement in the latter's activities. Some of its recommendations are general, but PCAST also makes specific recommendations based upon assembled panels as well as its own reviews of reports of the NSTC.

- **National Science and Technology Council (NSTC)** was established to integrate the President's S&T policy agenda across the federal government and ensure that S&T is considered in development and implementation of federal policies and programs. It is a policy and budgetary coordination body through which all executive departments and agencies coordinate S&T activities that require significant levels of interagency coordination. OSTP suggests topics around which the NSTC forms committees to review government spending in specific areas of research and recommend priority or allocation shifts. OSTP then advises agencies and OMB and solicits input from the larger scientific community about where priorities and resource allocation should focus. In preparation for FY2001, NSTC is overseeing the coordination and priority-setting for 11 areas of which the more mature, congressionally-mandated programs are managed as formal interagency crosscuts, while areas being developed for priority attention become the subject of NSTC working groups.
- **The Office of Management and Budget (OMB)** coordinates the President's budget process. This process starts each summer when agencies begin preparing their budgets for the fiscal year that begins in October of the following year. There is no "R&D budget" as such. OMB has the power to shape the budget, but does not set specific priorities for science. It does examine agency proposals for redundancy and looks for opportunities for interagency coordination. It has no means for truly setting priorities between different R&D programs with differing goals. Budget guidelines for R&D are issued jointly by OSTP and OMB. While agency officials report that the budget call does have some effect on R&D allocation, it may actually affect more how existing plans are labeled than on how budget priorities are set.

The priorities for R&D that become guidelines for the agency budgeting process are based on a set of goals named by the Clinton Administration in the first months of its tenure. These goals include: (1) a healthy, educated citizenry, (2) job creation and economic growth, (3) world leadership in science, mathematics, and engineering, (4) improved environmental quality; (5) harnessing information technology; and (6) enhanced national security. The R&D priorities have remained relatively stable over the past six years, with several additions, as illustrated in Figure S-3 below.

Figure S-3. R&D Priorities Set by the OSTP and OMB, FY96-FY01

FY96	FY97	FY98	FY99	FY00	FY01
Partnership for a new generation of vehicle					
Biomedical research, health promotion and disease and injury prevention research					
Learning and cognitive processes					
Materials technology					
Energy production and utilization technologies					
Integrated ecosystem management					
Networking and communications					
Human-computer interaction					
Counter-terrorism					
Detection, monitoring, and verification					
	Civilian aircraft				
	Telemedicine				
	Infectious diseases				
	Environmental risk assessment				
	Microelectronics				
		U.S. Global Climate Change Research			
			Plant genome research		
				Nanotechnology	

R&D Agencies Within the Executive Branch

The literature on agency-level R&D priority setting is not a robust collection. The Office of Technology Assessment report "Federally Funded Research: Decisions for a Decade" describes these activities, and this section draws heavily from that report. Beyond this, the agencies themselves have issued GPRA-inspired strategic plans that provide some insights into the priority setting process. Outside of these sources, we found very little concerning what happens in the agencies with regard to priority setting, despite there being over 20 government agencies funding R&D. It makes sense that the largest spenders would be the most well represented in the literature, but smaller agencies most likely make dearer trade-offs in funding. These smaller agencies may be worth further examination. Table S-2 below summarizes what exists in the literature about agency priority setting activities. Not all of these representations may be current. Some of the literature is dated and changes may well have occurred in these agencies since the original report was written.

Table S-2. Agency R&D Priority Setting Activities

AGENCY (IN ORDER OF THE MAGNITUDE OF THEIR R&D BUDGETS)	PRINCIPAL FINDINGS ABOUT PRIORITY SETTING ACTIVITIES REPORTED IN LITERATURE	METHODS USED TO IDENTIFY PRIORITIES
Department of Defense	Planning occurs in the office of the Director of Defense Research and Engineering (DDR&E) which looks to the NSTC and the Joint Chiefs of Staff's Joint Vision 2010 for guidance.	In its Basic Research Plan, DOD uses peer review and competition to achieve its objectives; Technology Area Reviews and Assessments (TARA) provide an oversight function to assess the quality of the research programs.
Department of Energy	A National Energy Strategy (NES) was designed to solicit input from the offices within DOE and from external advisors. Each program has an advisory panel, such as the High Energy Physics Advisory Panel (HEPAP) and the Energy Research Advisory Board (ERAB) which are external boards of scientists. These groups and others like them present to DOE a set of priority research areas that deserve the agency's special attention.	In selecting areas of research, the Office of Science emphasized the use of peer review to evaluate all programs. It also stated that advisory boards play a significant part in its priority setting processes.
NASA	NASA sets priorities in conjunction with the budget process and by selecting specific projects. Influenced more heavily by Congress than other agencies. The process is essentially bottom up with project managers proposing new initiatives. When large missions are proposed, such as Space Station Freedom, top-down direction determines the parameters of the effort. (OTA)	Priority setting results from a combination of input from NASA's own internal managers, staff and directors, and external actors like the National Research Council the Task Group on Space Astronomy and Astrophysics, and the space science community. In its goal to pursue scientific excellence, the Office of Science emphasized the use of peer review to evaluate all programs.
National Institutes of Health (HHS)	The director of each Institute, with the help of NIH's national advisory council, decides funding direction carried out through extramural grants and intramural programs.	Advisory councils are mandated by Congress and composed of people from both the scientific community and the public. The director also consults with intramural investigators, scientists in the extramural program, patients and their families interested in research on particular diseases, professional and scientific groups, representatives of the Administration and members of Congress, and with the public.
National Science Foundation	The NSF process for strategic planning involves calling in advisory committees and committees of visitors, regular reviews of programs and input from the National Science Board, and at the Directorate level reports from external groups on program issues. Goals are set "by scientific opportunity and the proposal process, as well as in special initiatives from advisory panels."	The NSB recommended that the following two criteria be adopted in place of the four criteria that had been used in the past to determine research priorities: • What is the intellectual merit of the proposed activity? E.g., does it advance knowledge and understanding in its own field and across fields? Is it creative and original? • What are the broader impacts of the proposed activity? E.g., advance discovery and promote teaching? Enhancing partnerships?
Department of Agriculture	USDA derives specific priorities from its 1997 strategic plan. Annual performance plans are modified based on input from the staff and advisory committees. Priority setting is advised by many groups, most important is the Joint Council on Food and Agriculture Sciences created by Congress.	Budgets are developed using a crosswalk that links the strategic goals and objectives of the agency with its overall budget structure and specific performance goals.
Department of Commerce, National Institute for Standards and Technology	NIST sets priorities in specific measurement areas based on the advice of councils created by NIST itself but which are established as independent nonprofit organizations as well as input from customers and NIST scientific and technical staff.	The councils strive to provide a consensus on industrial and academic requirements for standards and programs, including setting priorities. Divisions maintain direct contact with customers and manufacturers and conduct periodic customer surveys in order to set priorities based on customer need.
Environmental Protection Agency	EPA's Office of Research and Development (ORD) has the principal responsibility for research and development. Strategic Plans have relied heavily on EPA's Science Advisory Board (an independent group of engineering and science advisors) and expert panels convened by NAPA and the National Academy of Sciences	The most important of EPA's strategic principles is the explicit use of the risk paradigm to shape and focus EPA's organizational structure and research agenda, including hazard identification, dose response assessment, exposure assessment, and risk characterization.

CONGRESS

Of all the institutions involved in coordination and priority setting across fields of science, the literature as a whole shows its largest gap in its treatment of Congress. Congress has not paralleled the Executive branch in coordinating its own R&D policy, planning, and funding efforts. At least 21 Congressional Committees have direct federal R&D policy or funding responsibility. At no time in the Congressional process is there a comprehensive view taken of the R&D portfolio across the federal government. Further, there are a range of other legislative decisions that can affect planning and priorities of federal agencies and the conduct of federally-funded R&D. Regulatory, tax, or other decisions affecting research institutions are made outside of the Congressional circles in which R&D policy is decided and are frequently not coordinated with the Congressional entities having R&D policy jurisdiction.

INTERACTIONS BETWEEN THE EXECUTIVE AND LEGISLATIVE BRANCHES ON R&D

The need for interaction between branches causes the shortcomings found within each to become compounded by the lack of a formal coordinating mechanism. Since OMB must approve agency testimony, any formal presentation to Congress will serve to ratify the final decisions made during the Budget submission and will not easily provide a vehicle for an R&D agency to comment critically upon decisions made in that process. In addition, agencies are generally nonresponsive to questions of priority put to them by Congress. Yet, oversight hearings play a key role in determining the budgets of specific research programs and encouraging coordination between the research agencies. Absent a formal agreement, the budget, appropriations, and oversight processes constitute the coordination mechanisms and the conduct of this work is subject to individual agency and committee dynamics and is frequently left to the perspectives and proclivities of individual members of Congress and their staffs.

USE OF BENEFITS MEASURES IN PRIORITY SETTING AND BUDGET COORDINATION

With the introduction of new concepts of accountability, the R&D agencies have begun applying benefits measures to R&D and using the results to help set priorities. However, this process has not been studied or systematically documented. It may be too early in the process of adopting these measures to determine if they are effective. Most of the measures identified in the literature were adopted from private sector applications. In many ways, federal research presents greater problems for measurement and benchmarking than does private R&D. A great deal of federally funded research is directed to areas where the market is limited at best. Further, given the types of data available, the returns that result from most calculations must be interpreted as average rather than marginal rates. From a policy perspective, this means we cannot be certain from this aggregate analysis what the effect of an additional dollar of research expenditure might be. The cost/benefit framework itself may be too restrictive, failing to capture the many benefits that may be derived from publicly-funded basic research. The true

effect of such outlays may well be indirect, affecting productivity through changing the returns to private research and development rather than directly as a result of the specific research project.

Social rates of return analysis seeks to determine the sum of benefits accrued from changes in the knowledge base and compares these benefits to the cost of investment. This social benefit may be considerably greater than the private benefit taken in the form of profit. As a practical matter, such studies involve selecting a sample of specific innovations upon which to perform these calculations. This is both expensive and subject to unintentional or unavoidable bias in the selection process. Further, the social rate of return calculated by such means is not directly comparable to the internal rates of return calculated for private investment projects. Nevertheless, studies in this area have found a very high return to investment in basic research.

Among potential users of such information is, of course, Congress. Whether it acts as the originator of information requests for the purposes of furthering its own process, or is targeted as the ultimate audience for assessments produced for its benefit by the agencies coming before its committees for funding, Congress would like to have better means for determining the results ensuing from federal funding of R&D. Another body which has considered broad application of performance-based measures throughout the federal government is the NSTC. NSTC has issued a list of performance measures for function 250 (R&D) activities that encourage setting aside 80 percent or more of R&D for peer-reviewed competition as well as call for the majority of assessments to be made by external bodies. These are in reality guidelines for conduct and measures attuned to the first category found in the literature: asset-based measures.

The National Academy of Sciences Committee on Science Engineering and Public Policy (COSEPUP,) suggests general guidelines for measuring U.S. position in a given field of science: 1) What is the U.S. position in a field? 2) What key factors determine relative position? and 3) What is the trend for relative position in the near and long term? These yardsticks do not necessarily track well with the needs of mission agencies. Further, in practice, most measures appear to be of the asset-accounting type.

At the agency level, the DOE Office of Science Strategic Plan lists a series of success indicators for each of its five main goal areas (e.g.: "photochemical systems that hold promise for economical, highly efficient solar cells.") The indicators are outcome-oriented but seem to be of a checklist-type, attuned to achieving particular milestones and not quantitative in nature. They do not seek to track direct benefit back to specific R&D project outcomes

Documents on the performance assessment process in use by NSF point to heavy reliance on external assessment. Attempts are being made to shift from a somewhat ad hoc basis to a more formal procedure that will provide a common format to the review process that extends across NSF. For example, beginning in 1998, annual reports to the Director have been required from NSF units using a variety of indicators and data series to demonstrate effect.

Generally speaking, however, although new advances continue to be suggested in the academic literature and new methodologies for identifying and selecting new research, managing existing research, and evaluating and

assessing research retrospectively have been designed, the implementation of these methods by the research sponsoring community remains minimal.

CONCLUSIONS

The alternative approaches for managing the federal research enterprise that emerge from the literature fall into three areas:

- alternative readings of what are the appropriate *goals* federal research support should seek to fulfill;
- suggestions for alternative *mechanisms* for allocation of funds within the existing institutions for managing the federal research portfolio; and
- elements for a design leading in whole or in part to changes in those *institutional structures* themselves.

The two consistent themes are a desire to establish priorities and to do so in a coordinated fashion. This assumes that improvements in either the top-down or the bottom-up approach or both would improve the outcome. This assumption has not been questioned in the literature.

This is understandable. A frequent theme of the literature is that the federal R&D portfolio is only a *post facto* accounting concept. It is, by default, the aggregation of individual mission agency portfolios but is in no sense managed *ex ante* as a unified portfolio. Several studies advocate a greater role for the NSTC, OSTP, and/or OMB in setting portfolio guidelines at a higher level than that of the funding agencies as well as actively monitoring fulfillment. A necessary first step to effective prioritization, in other words, is to achieve coordination. Nevertheless, the issue of whether a more unified or better coordinated portfolio is desirable or achievable has not been adequately debated in the literature and deserves more attention.

A persistent assumption in the literature is that greater coordination is desirable and can be attained by setting high level goals and then proceeding to lower levels of decisionmaking authority. This seems problematic on two counts. First, decisionmaking in this area is embedded in existing institutions and political processes. Setting high-level goals and then rigorously enforcing them as the means for crafting priorities and making allocations on lower levels would, in effect, stand the present system on its head.

Second, such an approach may not accord with the evolving pattern for the commerce of ideas and knowledge management. Modern science is increasingly cross-disciplinary, with major discovery taking place at the interstices of traditional disciplinary categories. Contributing to this trend are increased globalization of effort with geographically dispersed working teams crossing geographic boundaries and an ever denser connectivity of information and ideas.

This is not to suggest that prioritization or coordination are undesirable or that gaining a measure of control is impossible. Rather, it is to suggest that as we proceed further along this line of inquiry we should address the following questions left largely unaddressed by the literature as it stands:

1. What do we mean by the terms "priority" and "coordination"?
2. What do we hope to achieve and how will we improve the public's lot through prioritization and coordination?
3. What are appropriate measures for identifying best practice in priority setting and coordination?

4. What alternative models, not necessarily predicated upon traditional views of either the science process or its effect on the larger society, need we consider to best develop means for achieving a true ability to set priority and the level of coordination we desire?

In order to fully understand the processes that take place within the system that result in the set of activities that the government labels "R&D" or "S&T" the Board needs a better understanding of what is happening in the agencies or in the scientific community in that "vast middle" between high level goals and bottom-up input. The decisions made at the program and project level have not been studied or described in the literature. Insights that could be gained from an examination of these activities may aid the Board in its effort to bring more accountability and coordination to the process.

1. INTRODUCTION AND METHODOLOGY

PURPOSE OF THIS REVIEW

The National Science Board is presently exploring how the U.S. federal government sets priorities in research and development and whether changes are needed in the decisionmaking process. Accordingly, the National Science Board Committee on Strategic Science and Engineering Policy Issues has identified the need for a comprehensive review of the relevant literature and experience on R&D priority setting across fields of science³. The purpose of this study is to provide input to the committee's consideration of the options for priority setting methodologies across fields of science to improve the federal R&D budget allocation process. This task is directed toward identifying and examining descriptions of the range of budget coordination and priority setting methodologies that are currently employed by the federal government as well as normative critiques of currently employed methodologies.

RAND was asked to examine the literature for insights into a set of questions posed by the NSB. These questions were posed in the original statement of work and elaborated upon in subsequent interaction between the project team and NSB staff. Taking these inputs together and placing them in a uniform framework has yielded a hierarchical outline of broad issues. In brief, the literature in this field was searched to provide insight into the following points:

- How does the literature describe the elements and structure of the system?
- What does the literature say about the functioning (measures/methods/models) of the system?
- Models of approaches to priority setting presented in the literature
- What critiques and suggestions exist in the literature?

As will be seen, not all of the enumerated points were equally well illuminated by the existing literature on the subject. In some cases, the literature as it stands was notably silent. Therefore different sections will be each handled in a manner appropriate to the level of discussion found in the literature. In each instance the discussion will provide a substantive overview of the search results as well as an assessment of the depth to which particular issues are covered.

³ As will be discussed in the Special Issues Section 1, there is a tendency for the terms "R&D" and "S&T" to be used as synonyms in the literature -- even in government documents. This report addresses itself to the coordination and prioritization of Federal support to research in science. Yet, we have mostly followed the usage found in the literature we report. By preference we have used the term "R&D" when referring to the formal apparatus or process by which such activities are funded.

OUTLINE OF THE REVIEW

What follows is a systematic review of recent literature on themes identified by the Committee as being of interest for its own deliberations and for those of the National Science Board as a whole. After this introduction and methodology section, the report presents an overview of literature describing the roles of different parts of the federal government as they interact to influence the direction of R&D.

Section two provides a narrative summary on the major institutions and organizations -- apart from the agencies charged with managing portions of the federal R&D portfolio -- who play a role in coordination and priority setting on the large scale. Section three moves the literature review to the level of the agencies and presents a brief review of what the literature presents as methods by which priorities are determined in each as well as to review cases of specific cross-agency research initiatives. Section four presents critiques of the current process and suggestions for change as they are discussed in the literature. Section five departs from a strict reading of the literature to make observations and suggestions, including those from the authors.

Special Issues Sections

Two "special issues" sections follow this discussion: the first calls the reader's attention to the presence of a serious definitional issue underpinning the NSB's larger inquiry. In order to address the questions raised by the Committee and the Board, an understanding of the usage of the terms "science and technology" ("S&T") and "research and development" ("R&D") is crucial. Failure to recognize both the distinctions between the two terms and the lack of cross-agency consistency in their use could prove sufficient to frustrate the best-intended effort to improve mechanisms for priority-setting and budget coordination across agencies and across fields of science. This section also addresses the question of relevant data sources. The second special issues section considers in brief the alternative measures proposed for assessing benefits, the extent to which the literature suggests they are employed, and identifies the databases that exist in various locales within the federal government which might assist in more coordination, systematic priority setting, and benefits assessment.

Attached to this report is an annotated bibliography of sources relevant to the NSB deliberations. While the report itself presents a thematic treatment of the literature in overview, the annotated bibliography provides a means to consider the contributions of individual papers and reports.

Methodology

This section describes the methods used to define, collect, and review the literature covered in this study. In order to identify the universe of literature relevant to this review, a set of initial core sources was obtained. The National Science Board in the original task statement nominated these core sources. We examined the

bibliographies of these core sources and added relevant materials to the list. In addition, we searched the RAND and the Science & Technology Policy Institute libraries and the personal holdings of the analysts associated with this effort for additional materials. Several earlier projects, including a National Academy of Sciences study, had developed bibliographies that could be used for this project, and we relied heavily upon these.

From the initial list, we then developed a set of terms to be keyed into various search engines. With this new material, we iterated our search methodology by examining the bibliographies of these reports and articles for any other relevant materials. At the same time, we reviewed the AAAS Science and Technology Policy Yearbooks for articles that would have relevance to the questions being asked by the NSB.

Once the results were processed, the project team examined the articles and reports discarding the material that did not address directly the questions of priority-setting, coordination, or measurement of R&D. Some materials that were discarded included articles that were of interest to the general category of R&D but that were not pertinent to the focus of this study, e.g., an article debating the merits of the federal R&D enterprise as a contributor to economic growth.

As this material was being collected, we developed an annotated bibliography. This bibliography was shared at several points with the NSB staff to be sure that we were identifying the most relevant literature. We amended our search strategies based upon the NSB feedback, by adding, for example, materials about performance measures and economic returns to R&D as they apply to priority setting. We did not attempt to resolve discrepancies among these sources. We relied solely on the literature and did not solicit the input of representatives from interested organizations, such as the NAS or AAAS to help develop a set of priority measures across fields of science.

Finally, in November 1999, we submitted a draft report to NSB that provided the results of the literature review, including the refined models for priority setting across fields of science, recommendations for the priority setting measures, and a method for verifying data submitted in the annotated bibliography. Based upon subsequent conversations and the comments from NSB staff on the earlier document, we have crafted the present effort.

2. INSTITUTIONS AND PRACTICES OF GOVERNMENT-WIDE COORDINATION AND PRIORITY SETTING

Goals, priorities, and budget allocation are all a part of a pluralistic system for creating the R&D budget, yet there is no formally defined process within the federal government to set goals and priorities or make allocation decisions for science. The process is iterative and complex. Many players with different interests interact to influence the outcomes. As the National Academy of Sciences has noted, as these players interact, the interests of science come up against other national goals and priorities, and funding for specific areas of science compete with one another for allocation of funds. (NAS, 1995, p. 4) The outcome is roughly balanced across many areas of science and targets a number of specific goals and priorities.

This section assesses the discussion in the literature of the broad goals for R&D with a particular focus on the government-wide organizations that play a large role in coordination and priority setting across fields of science.

SETTING GOALS – OPERATIONAL MODELS

There is a great deal of attention paid in the available literature to the question of goal setting for science. Most of the reports recommend ways that goals for science funding could be better set within the system, with the implicit criticism that the current political process no longer adequately serves the people's interests in the realm of science. The issues surrounding goal setting for science have taken on a new imperative in large part because the science and technology enterprise has entered a new era of funding challenges. This view is prevalent among most literature addressing these questions. (Council on Competitiveness 1996, Clinton and Gore 1994, NAS 1993) The challenges inherent in this new era arise from a number of factors, including the end of the Cold War, the information revolution, and the increasing use of science and technology in products prominent in the world economy. "As we approach the new millennium, these broad changes have recast the framework in which the U.S. research and development system functions." (NAS, 1993, preface)

Prominent among the reports recommending a more rational goals process for science funding is the National Academy of Sciences report, *National Goals for a New Era*, which recommends that 1) the United States should be among the world leaders in all major areas of science; and 2) the United States should maintain clear leadership in some major areas of science (1993, p. 19-20). These broad goals are echoed in the Clinton Administration report, *Science in the National Interest*, which, in addition to adopting the NAS recommendations, adds the goal that science should be conducted to "enhance connection between fundamental research and national goals." (Clinton and Gore, 1994, p. 7)

Among the reports addressing goal setting, recommendations fall into three broad categories:

- a shift from the current disaggregated approach to one tying the science funding to national goals such as health, environmental sustainability, energy, and so on; (Clinton and Gore, 1994; Carnegie, December 1992)
- a scientific goals approach which advocates cross-cutting assessments of existing government spending in areas of science and then a realignment of budgets, if needed, to better meet the needs of scientific advancement; (Merrill and McGeary, 1999) and
- a fine tuning of the existing complex, political process. (The "Ehlers Report," US Congress, 1998)

Criteria recommended for setting goals include assessing the extent to which science will help meet important goals, and the standing of U.S. science relative to capabilities in the rest of the world. Reports recommending changes to the goal structure for science are mainly made in reports from the National Academy of Sciences, the Carnegie Commission, and the Committee for Economic Development. Literature developed by groups closer to the process are less likely to discuss broad goal setting for science and more likely to focus on the question of how science priorities are set within the agencies.

Several reports address themselves to the broadest goal: how much is enough? The Office of Technology Assessment (OTA) notes "Questions such as 'Does the Nation need more science?' and 'How much research should the Federal Government support?' Have no ready answers. 'How much is enough' depends on the goals of the research system"(OTA, 1991, p. 10). The Clinton Administration's report, *Science in the National Interest*, suggests that "a reasonable long term goal for the total national R&D investment...might be about 3 percent of GDP," but the report does not offer a plan as to how to reach this goal (Clinton and Gore, 1994, p. 15). (During the Clinton Administration, R&D spending as a share of GDP has actually dropped.⁴) Leon Lederman suggests that the US should be spending twice the amount it was spending in 1968 and should increase spending by four percent per year. (1991, p. 6)

Literature focusing on goals-based priority setting has also acknowledged new challenges and explored new models. This literature often refers back to larger goals, but then points to specific disciplines of science that need attention. Models for priority setting in the ideal fall into three broad categories:

- Engaging the scientific community in determining priorities based on scientific needs, linking priorities to upstream and downstream connections and benefits. (Carnegie Commission, 1992)
- Benchmarking U.S. capabilities in specific fields against those of other nations and determining where more (but rarely less) emphasis might be placed to help bolster a specific area of science. (NAS 1998; 1993)

- Having agencies seek input from scientists and stakeholders on priorities in science that will help meet government missions like space science or energy science. (U.S. Congress 1998)

The practice of priority setting at the agency level will be considered in section three. What follows is an examination of what the literature has to say about government-wide players and the processes of coordination and priority setting at the supra-agency level.

EXECUTIVE BRANCH ORGANIZATIONS

Scientific disciplines overlap agency jurisdictions, making attempts to coordinate the federal R&D portfolio more difficult.⁴ The need to coordinate Executive Branch R&D activities was recognized by Congress in the National Science and Technology Policy, Organization, and Priorities Act of 1976, which established the Office of Science and Technology Policy, the Presidents Committee of Advisors on Science and Technology (PCAST), and the Federal Coordinating Council for Science, Engineering, and Technology, the interagency entity that was the precursor to the National Science and Technology Council (NSTC). This structure, together with the operations of the Office of Management and Budget (OMB), the body charged with coordinating R&D policy, planning, and funding decisions between agencies. However, the actual operation and effectiveness of these processes in coordinating R&D policy, planning, and funding is poorly described in the literature.

The Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) in the Executive Office of the President, under the direction of the Assistant to the President for Science and Technology, provides a resource for scientific and technical information within the government and plays a role in coordinating R&D activities throughout the agencies and ensuring comprehensiveness in the budget for science activities. The science advisor and his staff serve as advisors to the President, and so act to implement the President's policy. (OTA, 1991, p. 74) "OSTP has the access to outside expertise and the focus on sciences, but its role in the budget process is subordinate to OMB." (Teich, 1991)

OSTP helps to coordinate federal science activities to meet the President's goals. This is primarily done, in the Clinton Administration, through the National Science and Technology Council (NSTC) for which OSTP acts as a secretariat. The Executive Office of the President, through the science advisor and NSTC, has developed

⁴ U.S. Gross Domestic Expenditure on R&D (GERD) as a percentage of Gross Domestic Product (GDP) has decreased from 2.74 percent in 1992 to 2.64 percent in 1997. Source: OECD's Main Science and Technology Indicators 1998, volume 2, table 5.

⁵ This section relies heavily on the 1991 Office of Technology Assessment report, "Federally Funded Research: Decisions for a Decade," which is by far the most comprehensive source of information on the roles of the different parts of government in setting goal and priorities, in allocating funds, and in coordinating research activities.

mechanisms to review specific areas (such as environment and natural resources, information and communication, or transportation R&D).

Joint OSTP-OMB Priority Memos

OSTP, together with the Office of Management and Budget, issues a budget memorandum to the agencies each year on R&D priorities. The guidance provided is developed through the NSTC process, which includes representation from all the R&D agencies. The priorities are established based on a set of goals established by the Clinton Administration in the first months of its tenure. These goals included: (1) a healthy, educated citizenry, (2) job creation and economic growth, (3) world leadership in science, mathematics, and engineering, (4) improved environmental quality; (5) harnessing information technology; and (6) enhanced national security. In as much as there is no clear statement as to how priorities are to be derived from these goals, it is useful to look at recent budget memoranda for insights into this process. (Gibbons and Panetta, 1994)

The Administration uses a memo issued jointly by the OSTP and the OMB to help set priorities in science and technology. Table 2-1 shows the evolution of research priorities named by the Clinton Administration.

Table 2-1: Changing Priorities for R&D within the Clinton Administration

FY96	FY97	FY98	FY99	FY00	FY01
Partnership for a new generation of vehicle					
Biomedical research, health promotion and disease and injury prevention research					
Learning and cognitive processes					
Materials technology					
Energy production and utilization technologies					
Integrated ecosystem management					
Networking and communications					
Human-computer interaction					
Counter-terrorism					
Detection, monitoring, and verification					
	Civilian aircraft				
	Telemedicine				
	Infectious diseases				
	Environmental risk assessment				
	Microelectronics				
		U.S. Global Climate Change Research			
			Plant genome research		
				Nanotechnology	

As part of the budget process, the FY1996 budget memo says that the NSTC Committees “will work with OSTP and OMB using Circular A-11’s R&D Exhibits to collect data on the programs that contribute to the identified priorities.” The memo notes that “Continual efforts to stimulate and coordinate the integration of cross-agency initiatives” will be undertaken. (Gibbons and Panetta, 1994; p. 15) In its instructions, the two offices also call for a series of “crosscuts” in education, transportation, construction, computing, environment, and fundamental science. (Gibbons and Rivlin, 1995; p. 10)

Crosscuts

In addition to naming research priorities, the joint memos also ask the agencies for information on “Crosscutting” themes in S&T. The FY 2000 joint OSTP-OMB budget call naming priorities for R&D notes that “NSTC coordinated selected interagency science and technology investment priorities.....managed as interagency crosscuts.” (Jones and Lew, 1998; p 2.) The crosscuts listed in the FY 2000 memo are limited to four:

- Climate Change Technology Initiative
- U.S. Global Climate Change Research
- Partnership for New General of Vehicles
- High Performance Computing and Communications.

In the OSTP-OMB joint memo naming priorities for FY2001, only two formal crosscuts are included in the budget call:

- Information technology R&D, and
- U.S. Global Climate Change Research.

President's Council on Advisors on Science and Technology (PCAST)

PCAST advises the President through the Assistant to the President for Science and Technology. Beyond that, according to the Executive Order 12882 defining the role for PCAST, its principle task is to assist the NSTC in securing private sector involvement in the latter's activities. (EOP(a), 1993) In its own Statement of Principles, PCAST emphasizes the need for strong support of both basic and applied research and presses for funding stability to sustain multi-year efforts. (PCAST, no date) Some of the recommendations are general in nature; for example, in a 1996 letter to the President, PCAST outlined their view of major research priorities that should instruct funding for the 4-year span of the Administration's term. (PCAST, 1996) Beyond this, PCAST has assembled review panels and ordered studies to examine specific issues, such as the PCAST Fusion Review Panel report on the U.S. program of fusion energy R&D, and made recommendations therein about specific areas of research. (PCAST, 1995)

PCAST also makes recommendations based on its own reviews, from technical and budgetary perspective, of reports of the NSTC. The National Nanotechnology Initiative is an example of recent PCAST influence on the priority setting process: PCAST studied the possibilities for nanotechnology and incorporated its findings in a letter to the President recommending nanotechnology as a new priority. (PCAST, 1999) This was apparently an important step in getting this cross-agency and cross-field initiative underway. (See Table 2.1)

The National Science and Technology Council

The National Science and Technology Council was established, according to the Executive Order (12881) creating it, to coordinate the S&T policymaking process and to "integrate the President's S&T policy agenda across the Federal Government." Further, the Order states that NSTC should "ensure S&T are considered in development and implementation of federal policies and programs." (EOP(b), 1993)

All executive department [sic] and agencies...shall coordinate S&T policy through the council and shall share information on R&D budget requests....The Council shall develop for submission to the Director of the Office of Management and Budget recommendations on R&D budgets that reflect national goals. In addition, the Council shall provide advice to the Director of the Office of Management and Budget concerning the agencies' R&D budget submissions. (EOP(b), 1993)

This purpose of NSTC is made clearer in its' 1998 Annual Report.

Federal departments and agencies have identified a set of R&D areas that are important national efforts requiring coordinated investments across several agencies...This budget guidance, rather than providing an exhaustive list of all Administration R&D priorities, focuses on those activities that require significant level of interagency coordination. (NSTC, 1998)

Thus, it is the exceptional R&D initiative that is coordinated throughout the government by NSTC and it is the agencies themselves within the framework of NSTC rather than NSTC as a separate supervisory entity that carry forward this work.

Available government documents indicate that the NSTC takes an active role in priority setting as well as coordination. According to the April 22, 1999 Lane-Lew memorandum, the NSTC convenes during the budget process to "review the S&T investment portfolio and help ensure the strongest possible R&D budget proposal for the [fiscal year]." (p. 1) In addition, the memo notes that the NSTC "coordinates a small number of selected interagency science and technology investment priorities." For example, in preparation for fiscal year 2001, the NSTC is overseeing the coordination and priority-setting for 11 areas. Of these 11 areas, the more mature, congressionally mandated programs are managed as formal interagency crosscuts, while areas being developed for priority attention become the subject of NSTC working groups designed to develop programs. The NSTC programs include a definition of activities, an inventory of existing budgeted research, and an implementation plan for coordination and allocation (Lane and Lew, 1999, p. 2).

NSTC is organized as a series of standing committees covering broad aspects of the portfolio defined by national goals for S&T who, in turn, may form working groups (task forces, programs) to address particular issues. As an example, the NSTC Committee on Science has subcommittees addressing a variety of substantive issues as well as those, such as the subcommittee on biotechnology which "addresses research opportunities in aspects of biotechnology, resources and infrastructure needed for biotechnology research, and international aspects of biotechnology." (NSTC, 1998; p. 23)

The role of the NSTC is cited in several reports as playing a key role in priority setting and coordination. David Z. Robinson notes that the Executive Office of the President, through the president's science advisor and the NSTC, "has developed mechanisms to review specific areas (such as environment and natural resources, information and communication, or transportation R&D). Where duplication of effort and gaps can be identified, trade-offs can be made. These crosscuts are indeed useful and have led to improved efficiency. Trade-offs are made among compatible activities and they make sense" (Robinson, 1997; pp. 218-19) Robinson does not detail how these tradeoffs are conducted.

The Office of Management and Budget

The Office of Management and Budget compiles the President's annual budget, seeking within constraints to support the President's policies, programs, and commitments. The formal process starts each summer in the Executive Branch when the agencies begin preparing their budgets for the fiscal year beginning in October of the following year. Each summer, budget guidelines for R&D are issued jointly by OSTP and OMB. These guidelines, discussed above, work more as a budget call, asking agencies to report on their plans to conduct R&D in specific priority areas. OMB reviews, coordinates, and scrubs the budget, resolves any disagreements, and submits the budget to Congress in late January or early February. There is no "R&D budget" as such: there are many R&D budgets embedded in the budgets of 21 federal departments and agencies that conduct or support R&D. The R&D requests are handled in the budget process as parts of the agency's total budget. (Shapely, 1992.)

OMB has the power to shape the budget, but ensuring that the budget responds to the President's priorities for research are only a small part of its responsibilities. The OMB has responsibility to examine agency proposals

for redundancy and looks for opportunities for interagency coordination. Although the (pre-NSTC) OTA study cited OMB as "a surrogate for a crosscutting agent" within the federal system, (OTA, 1991, p. 14), priority setting across different areas of science or among the different R&D budgets does not occur at OMB:

Setting priorities implies a 'trade-off' area composed of the programs to be prioritized and some agreed-on criteria for deciding priorities. Priorities may meaningfully be set for programs having the same or similar goals. But between programs for independent goals, or when the programs have multiple goals, priority setting is essentially arbitrary. The major federal R&D programs have different goals, and the major budgetary decisions on them are largely independent of each other (Shapley, 1992, p. 10).

Although a number of reports and analyses call for OMB and others within the budget process to evaluate the R&D portfolio in terms of its progress towards national goals, in Shapley's view, efforts at priority setting for R&D should not involve trade-offs within the budgets dedicated to R&D spending. These are essentially political judgments, he claims, and need to be placed within the total budgetary process:

R&D budgets should be considered primarily in relation to their program goals, not in relation to R&D for other goals. The relative priorities of the many independent program goals must be set arbitrarily in the political process....There is no reason why R&D programs or major initiatives directed at different goals...should be expected or required to compete only with each other in the budget process. These and the goals they are to serve should compete with all other proposals in the federal budget (Shapley, 1992, p. 11).

OMB expects the scientific community to work with them on these priority areas by helping to: 1) identify the implications and priorities of all the programs that the OMB is trying to put together; 2) explain the programs, to scientists, Congress, and others, 3) reinvent programs when necessary. (Glauthier, 1995)

CONGRESS

Of all the institutions involved in coordination and priority setting across fields of science, the literature as a whole shows its largest gap in its treatment of Congress. As the source of all the resources to be used in building and sustaining the federal research portfolio its role is crucial, yet its methods and processes appear to have been less amenable to exposition than in the case of other institutions.

While having provided the Executive Branch with a means to coordinate R&D through the 1976 Science Policy Act, Congress has not made a parallel effort to coordinate its own R&D policy, planning, and funding efforts. At least 21 Congressional Committees have direct federal R&D policy or funding responsibility (OTA, 1991; p. 83)⁶. Nine of the thirteen appropriations subcommittees have R&D responsibilities (Carnegie Commission, 1994). In addition, the committee structure and jurisdictional boundaries between the House of Representatives and Senate are different, further complicating comprehensive policy and budget coordination. (OTA, 1991; Shapely, 1992; Carnegie, 1994)

⁶ Note that this figure results from adding the two budget committees and the two appropriations committees to the totals reported in the OTA study.

At no time in the Congressional authorization or appropriations process is there a comprehensive view taken of the R&D portfolio across the federal government. While numerous studies have cited the need for this coordination, Congress has not responded and a major shortcoming still exists. (NRC, 1993; NAS 1988; Carnegie Commission 1993, among others)

Other structural and legal impediments exist to impede comprehensive coordination of R&D policy and budgets within Congress. For most of the last decade, the budgets of the defense functions and the civilian functions have been kept separate by budget "firewalls" enacted after the end of the Cold War to prevent the raiding of the defense budget to pay for civilian program increases. With over half of the federal R&D budget in the defense programs (budget function # 050), these "firewalls" effectively thwart efforts to coordinate R&D policy, planning, and funding within Congress. (Carnegie, 1994) So at the Congressional level, for example, coordinating the Navy oceanographic budget with the oceanographic budget at NSF and NOAA would be difficult.

Another impediment to adequate coordination in Congress has been the reduction in the role that Congressional support agencies play in advising Congress on R&D policy, planning, and funding issues. Of primary importance was the termination of the Congressional Office of Technology Assessment (OTA). More recently, the Congressional Research Service (CRS) merged its Science Division into another division, effectively downgrading the R&D program analysis functions. Reports have cited the role of Congressional support agencies in helping Congress (Carnegie Commission, 1991; 1994) and urged a strengthening of their role in providing expert advice to legislators. Given these earlier findings, the elimination of the OTA and changes at CRS can be viewed as making more effective coordination of R&D policy more difficult.

In addition to the direct funding decisions made by Congress there are a range of other legislative decisions that can affect planning and priorities of federal agencies and the conduct of federally-funded R&D. Regulatory decisions (disposal of toxic chemicals used in research, treatment of laboratory animals), tax decisions (R&D tax credit extension), or other decisions affecting research institutions (immigration visa ceilings, graduate medical education subsidies) can all affect R&D programs. Yet these decisions are made outside of the Congressional circles in which R&D policy is decided and are frequently not coordinated with the Congressional entities having R&D policy jurisdiction. (Carnegie, 1994.)

Interactions Between the Executive and Legislative Branches on R&D

In addition to the processes within each of the Executive and Legislative branches of government, decisions on agency funding and operations involve an interaction between the branches as well. The Executive Branch proposes budgets, agency operational plans and GPRA reviews and Congress acts on those recommendations and reports. Because of the need for this interaction, the shortcomings found within each branch of government become compounded by the lack of a formal coordinating mechanism between the Branches.

Congressional interaction with the Executive Branch on R&D issues occurs in a variety of ways. The most visible forms occur during the budget and appropriations process each year, since R&D functions are funded out of the discretionary budget and are thus subject to annual appropriations. But as has been noted above there are

limitations on both ends of Pennsylvania Avenue that prevent this interaction from accomplishing the level of coordination between the branches of government that many participants express as their desire.

In addition, any formal interactions are somewhat stilted and confined. Since OMB must approve agency testimony, any formal presentation to Congress will serve to ratify the final decisions made during the budget submission and will not easily provide a vehicle for an R&D agency to comment critically upon decisions made in that process. In addition, agencies are generally nonresponsive to questions of priority put to them by Congress, since any admission of a lower priority for a program has usually resulted in a funding cut, especially during the deficit reduction efforts that have marked the last decade. (Shapely, 1992)

One tool that has been increasingly used by Congress since the mid-1980's to communicate its priorities for federal spending is "earmarking." This process of designating institution-specific funding has been discussed widely as a violation of the peer-review process of selecting research priorities (Carnegie, 1994). But this does constitute a frequently used means of communicating R&D funding priorities between the Congress and the Executive Branch agencies.

Separate from the appropriations process is the role that the authorizing committees play in conducting reviews of federal programs. In the R&D area, Congressional oversight is the systematic review of programs by authorizing committees that seek to address the problems of research management and priority setting outside of the annual appropriations process. These efforts have been important in shaping the direction and funding of federal programs. Problems exposed during oversight hearings on the Superconducting SuperCollider were ultimately responsible for its cancellation. These oversight hearings play a key role in determining the budgets of specific research programs and encouraging coordination between the research agencies. (OTA, 1991)

But while studies have sought improved coordination of R&D policy, planning, and funding between the two branches of government, as mentioned above, no formal mechanism has emerged. Absent a formal agreement, the budget, appropriations, and oversight processes constitute the coordination mechanisms and the conduct of this work is subject to individual agency and committee dynamics and is frequently left to the perspectives and proclivities of individual Members of Congress and their staffs.

3. PRIORITY SETTING: AGENCY PERSPECTIVES AND CASES

This section presents the description of alternative models for priority setting in different agencies as revealed in the literature. To provide further illumination, albeit from a different angle, this section also presents cases, as described in the literature, of how some specific cross-agency research initiatives were initiated.

PARALLEL ASSESSMENTS FOR DIFFERENT AGENCIES INVOLVED IN PRIORITIZING R&D

The literature on agency-level R&D priority-setting is not a robust collection. The Office of Technology Assessment report "Federally Funded Research: Decisions for a Decade" describes these activities, and, even though the report is now 10 years old, this section draws heavily from that report because no report has updated it. The agencies themselves have issued GPRA-inspired strategic plans that provide some insights into the priority setting process.

Outside of these sources, we found very little on what goes on in the agencies regarding priority setting, despite the fact that there are over 20 government agencies spend R&D money. It makes sense that the largest spenders would be the most well represented in the literature, but smaller agencies most likely make dearer trade-offs in funding, and thus may be more interesting to study. Table 3-1 below summarizes what we found in the literature about agency priority setting activities (the full text description is in Appendix A.) Not all of these representations may be up-to-date. Some of the literature is dated and changes may well have occurred in these agencies since the original report was written..

As OTA described it, "Within agency research programs, research proposals have traditionally been selected for support on the basis of expert peer or program manager judgments of scientific merit and program relevance." (p. 96) Moreover, as noted in Section 2 above, each agency defines R&D somewhat differently depending upon its mission. As the OTA study noted:

"Each agency has its own culture, which contributes not only to its success, but also embodies historically the "way things are done." Agency culture is thus a powerful determinant of future directions, with specific goals reflected in the collective knowledge of agency personnel. Pluralism and decentralization characterize each of the research agencies, with many separate programs pursuing diverse objectives. In particular, the lines of decisionmaking within an agency are more complicated than any organizational chart would suggest." (p. 97)

As Christopher Hill has written, "R&D spending responds to national crises; political and budgetary imperatives; and occasionally, to determined efforts of highly committed interests pursuing long-term visions of a different future." (Hill, 1995) No single model of decisionmaking exists to illustrate these mechanisms. Although there are some similarities in approach, each agency has a different set of decisionmaking processes to aid priority setting.

AGENCY (IN ORDER OF THE MAGNITUDE OF THEIR R&D BUDGETS)	PRINCIPLE FINDINGS ABOUT PRIORITY SETTING ACTIVITIES REPORTED IN LITERATURE	METHODS USED TO IDENTIFY PRIORITIES	SPECIAL OR UNIQUE METHODS USED WITHIN THE AGENCY	GAPS IN LITERATURE	SOURCES OF INFORMATION ABOUT AGENCY'S PRIORITY SETTING ACTIVITIES
Department of Defense	Planning occurs in the office of the Director of Defense Research and Engineering (DDR&E) which looks to the NSTC and the Joint Chiefs of Staff's Joint Vision 2010 for guidance.	In its Basic Research Plan, DOD uses peer review and competition to achieve its objectives; Technology Area Reviews and Assessments (TARA) provide an oversight function to assess the quality of the research programs.	DARPA managers fund good <i>ideas</i> that are on the forefront of technology development to meet desired objectives. Other services the services "show remarkably little fluctuation in allocated funds, adjusted for inflation"—priority setting is based on previous activities	Very little available about Office of Naval Research priority setting	OTA; DOD Annual reports; GPRA documents; RAND reports
Department of Energy	A National Energy Strategy (NES) was designed to solicit input from the offices within DOE and from external advisors. Each program has an advisory panel, such as the High Energy Physics Advisory Panel (HEPAP) and the Energy Research Advisory Board (ERAB) which are external boards of scientists. These groups and others like them present to DOE a set of priority research areas that deserve the agency's special attention.	In selecting areas of research, the Office of Science emphasized the use of peer review to evaluate all programs. It also stated that advisory boards play a significant part in its priority setting processes.	The R&D and Technology Roadmapping Framework in the DOE strategic plan states that "Each planning team shall ensure that the R&D technology roadmaps development under the direction of the Under Secretary are fully integrated into the goals, objectives, performance goals, and strategies of the strategic plan. Laboratory input will be necessary to accomplish this."	Little available about internal mechanisms within DOE to help set priorities	OTA; DOD Office of Science planning documents
NASA	NASA sets priorities in conjunction with the budget process and by selecting specific projects. Influenced more	Priority setting results from a combination of input from NASA's own internal managers, staff and directors, and external actors like the National	In the 1997 Strategic Plan, the OSS proposed near-term (2000-2004) and long-term (2005-2020) priorities. The plan	Not clear from literature how NASA decides on specific	OTA; NASA Strategic Plans; GPRA documents:

National Institutes of Health (HHS)	heavily by Congress than other agencies. The process is essentially bottom up with project managers proposing new initiatives. When large missions are proposed, such as Space Station Freedom, top-down direction determines the parameters of the effort. (OTA)	Research Council the Task Group on Space Astronomy and Astrophysics, and the space science community. In its goal to pursue scientific excellence, the Office of Science emphasized the use of peer review to evaluate all programs.	established seven fundamental questions that form the foundation for the office's scientific program. It then incorporated the advice of the NRC as well as others in the space science community in establishing "Enterprise Goals" * "Science Goals", and more specifically, "Science Objectives".	missions or on how disinvestments are made.	National Research Council reports
	The director of each Institute, with the help of NIH's national advisory council, decides funding direction carried out through extramural grants and intramural programs.	Advisory councils are mandated by Congress and composed of people from both the scientific community and the public. The director also consults with intramural investigators, scientists in the extramural program, with groups of patients and their families interested in research on particular diseases, with professional and scientific groups, with representatives of the Administration and members of Congress, and with the public.	When institute staff "notice evidence of an emerging area of research, they assess the importance of the new field and gauge interest and capabilities. They can then convene a meeting or workshop, write up a proposal for a new program, and go to their council for approval. If the program does not have a known constituency, an institute will often issue a request for applications."	The priority setting process is better described in literature for this agency than for others. Little description exists of coordination efforts across the Institutes or between the Department and other departments of government.	NIH report, "Setting Research Priorities at the National Institutes of Health" (1997); OTA; National Research Council Review
National Science Foundation	The NSF process for strategic planning involves calling in advisory committees and committees of visitors, regular reviews of programs and input from the National Science Board, and at the Directorate level reports from external	The NSB recommended that the following two criteria be adopted in place of the four criteria that had been used in the past to determine research priorities: • What is the intellectual merit of the proposed activity? E.g., does it advance knowledge and	Setting NSF apart from other agencies is the role of the Congressionally-chartered National Science Board (NSB) in priority setting.	Little description exists of coordination efforts among the Divisions of NSF.	NSB planning documents; NSTC review; OTA; GRPA documents

* The OSS intends to accomplish the scientific investigations related to Enterprise and Science goals within a five to six year time frame.

groups on program issues. Goals are set "by scientific opportunity and the proposal process, as well as in special initiatives from advisory panels."	understanding in its own field and across fields? Is it creative and original? • What are the broader impacts of the proposed activity? E.g., advance discovery and promote teaching? Enhancing partnerships?	The majority of funds are "formula funds" or "line item" appropriations determined by Congress. Agency discretion to set priorities is limited.	Very little critical review has been conducted of USDA's priority setting process.	GRPA annual performance plans; OTA
USDA derives specific priorities from its 1997 strategic plan. Annual performance plans are modified based on input from the staff and advisory committees. Priority setting is advised by many groups, most important is the Joint Council on Food and Agriculture Sciences created by Congress.	Budgets are developed using a crosswalk that links the strategic goals and objectives of the agency with its overall budget structure and specific performance goals.			
Department of Agriculture				
NIST sets priorities in specific measurement areas based on the advice of councils created by NIST itself but which are established as independent nonprofit organizations as well as input from customers and NIST scientific and technical staff.	The councils strive to provide a consensus on industrial and academic requirements for standards and programs, including setting priorities. Divisions maintains direct contact with customers and manufacturers and conducts periodic customer surveys in order to set priorities based on customer need.	The Council for Optical Radiation Measurements (CORM) was established in 1972 to determine "Pressing Problems and Projected National Needs in Optical Radiation Measurement". CORM is composed of members from government, industry and academia.	Very little was available from or about NOAA on priority setting	Congressional testimony; OTA; GPRA documents
Department of Commerce, National Institute for Standards and Technology				
EPA's Office of Research and Development (ORD) has the principal responsibility for research and development. Strategic Plans have relied heavily on EPA's Science Advisory Board (an independent group of engineering and science advisors) and expert panels convened by NAPA and the National Academy of Sciences	The most important of EPA's strategic principles is the explicit use of the risk paradigm to shape and focus EPA's organizational structure and research agenda, including hazard identification, dose response assessment, exposure assessment, and risk characterization.			NAPA report; NRC report; EPA strategic plan; OTA
Environmental Protection Agency				

CASES OF INTER-AGENCY PRIORITY SETTING ACROSS FIELDS OF SCIENCE

This subsection briefly describes several representative cases of research initiatives to illustrate priority setting found in the literature. The literature is not sufficient to provide all one would wish to know about cross-agency priority setting across fields of science. This is both due to a paucity of documentation and to the fact that actual initiatives may come about outside of the channels and procedures the literature describes. Anecdotal cases gleaned from the literature, those that have not been formally produced as case studies, generally are characterized by the difficulty of capturing the crucial "pre-history" of the initiative, that is the period before it entered the formal process.

Partnership for a New Generation of Vehicles

The Clinton Administration's Partnership for a New Generation of Vehicles (PNGV) which began its existence as the so-called Clean Car Initiative, is an example of a multi-million dollar, interagency R&D effort whose origin lies largely outside the formal system for coordination. It is true that the initiative can trace its lineage back to the FCCSET in the latter days of the Bush Administration. That body formed the Advanced Manufacturing Technology Initiative. Arising from then prevalent concerns over U.S. industrial and technological competitiveness, it sought to promote synergy in manufacturing R&D in general throughout the government.

In the early days of the Clinton Administration, an inter-agency working group began to look at the automotive industry. This group began to outline what technology goals might be feasible and desirable for this industry in particular.

Another thread was the contemporaneous concern over the fate and mission of the national laboratories. After the end of the Cold War, there was a general, unfocused interest in drawing upon the talents and output of the labs to further a wider national goals agenda. One means for doing so was to allow, through the establishment of cooperative R&D agreements (CRADAs), national laboratory personnel and working groups to work with and for private industry on well-defined research projects.

Nevertheless, PNGV came about as a political directive outside of the formal R&D coordination apparatus as it then existed. "Word came down...that 'the President wants to do a clean car'" (Chapman, 1998). The initiative was not in the final budget that was given by OMB to the White House in 1995 after months of deliberations by the agencies. Rather, it appeared at the end of the process, when the budget was announced. At the time, this directive resulted in a great deal of scurrying about by the agencies to figure out what the initiative was. As a result and only after the fact, a great deal of existing research was redesignated as Clean Car work and constituted the bulk of the original new initiative.

National Nanotechnology Initiative

The National Nanotechnology Initiative is the most recent of the large, visible cross-agency research efforts inaugurated by the current apparatus for coordination and priority setting. NSTC commissioned the creation of an Interagency Working Group on Nanotechnology (IWGN). IWGN was a task force composed of representatives of a wide range of research-sponsoring federal agencies as well as those for whom this issue area is of potential importance in consideration of their agency missions. The IWGN deliberated and issued a report calling for a federal initiative in this area (NSTC, 2000). PCAST then made recommendations based upon its own review, from technical and budgetary perspective, of the comprehensive report of the IWGN. The result was a letter to the President stating that the members of PCAST "believe that the Administration should make NNI a top priority." (PCAST Letter, November 1999) The President then made formal announcement of the NNI in January 2000 at CalTech.

In its review, PCAST identified the federal role as being appropriate due to the present distance of the relevant science (and, indeed, a great share of the technology) from most commercial applications. The members in their review also draw attention to the inter-disciplinarity required to pursue the R&D in this field. They note, in their capacity as a bridge to business, that the effort required would be "incompatible with many current corporate structures." (PCAST Review, November 1999):

There is a clear need for Federal support at this time. Appropriately, Federal and academic investments in nanotechnology R&D to date have evolved in open competition with other research topics, resulting in some fragmentation and duplication of efforts...Nanotechnology will require a somewhat more coherent, sustained investment in long-term research. The NNI would support critical segments of this research and increase the national infrastructure necessary to conduct it. (op. cit., p.2)

The initiative is judged favorably in providing balanced funding across "fundamental research, grand challenges, centers and networks of excellence, research infrastructure, and education and training." As a result of these factors, the document designates this as a field of endeavor requiring multi-agency effort and suggests that the NRC would be an appropriate external body to provide an annual review of performance under the NNI. Interestingly, PCAST also noted that changes in technology this profound could potentially lead to unforeseen ethical and moral questions. In their review they explicitly suggest that a "modest" amount be set aside for the study of such implications from nanotechnology.

AIDS Research

A third example of a shift in R&D priorities is the rapid increase in government spending on AIDS research. Lobbying by interest groups (such as the Treatment Action Group or TAG) had an affect on Congressional appropriations for health research. In addition, as a result of external pressure, the National Institutes of Health has convened several study groups to make recommendations explicitly targeted at AIDS research. In order to help prioritize funding in the area of AIDs-related research, the NIH Office of

AIDS Research (OAR) in 1994 formed an advisory council to help identify whether AIDS funding should be increased and, if so, in what areas of science these increases should be made.

The final report of the Advisory Council to the OAR makes a series of recommendations designed to further enhance the NIH AIDS research program by "creating more effective coordination of the endeavor and identifies several key scientific areas that warrant special emphasis" (accompanying letter, Charles C.J. Carpenter, M.D., Chair Office of AIDS Research Advisory Council.) The report recommends an increased emphasis on investigator-originated research and a reinvigoration of research efforts in vaccine and prevention research. The report makes a long list of recommendations for AIDS research, including:

- increase support for and improve peer-review of investigator-initiated research
- establish a restructured trans-NIH vaccine research effort
- augment research efforts to better understand the human immune system
- develop a comprehensive NIH HIV Prevention Science Agenda. (Report Of The NIH AIDS Research Program Evaluation Working Group Of The Office Of AIDS Research Advisory Council, March 14, 1996.)

The report had some influence on the way in which AIDS research funds were allocated, according to an article in the New York Times (March 14 1996). Nevertheless, the Executive Office did not enact one of the principle recommendations, preserving a central allocative authority for AIDS research funding. A number of administrative changes were made which led to funds for AIDS research to be allocated among various agencies rather than through a central office:

OAR chief William Paul was informed by the Office of Management and Budget that the 1996 AIDS budget would go directly to each NIH institute. OAR, backed by the Clinton Administration, had lobbied hard to prevent this, contending the office should retain the budget authority Congress gave it 3 years ago. OAR's independence was cast into doubt by a legal technicality that Congress included in the January resolution that funded NIH through 1996 (*Science*, 19 January, p. 281).

Congress did so despite protests from prominent scientists and AIDS activists that the move would prevent OAR from responding to a massive review of AIDS research. Although OAR didn't like the situation, it urged viewing this change in perspective in that the new rule applied only to the 1996 budget, which OAR has already shaped. Yet, Congress's action was viewed as "significant" since it affected OAR's ability to make changes in NIH's AIDS portfolio recommended by the research review. "If we had the authority this year, we would have used it," says Paul. (*Science*, March 1, 1996)

Astronomy and Astrophysics

A fourth and final look at specific cases of shifts in R&D priority setting focuses on the potential influence of a scientific community on the spending on R&D as well as the directions for science and technology in their field.

For the past four decades, astronomical and astrophysical communities have influenced federal spending in their field. By establishing priorities, and reporting them to relevant government agencies and the U.S. Congress,

the National Research Council's Astronomy and Astrophysics Survey Committee has had direct input into the priority setting process. Beginning in 1964 with the work of the Whitford Committee, this scientific community has reported each decade on the priorities for that field of science in ways that have charted the path of research in astronomy and astrophysics. (NAS website)

The surveys of scientists sponsored by the National Academy of Science Committee on Astronomy and Astrophysics (CAA) have resulted in these reports. The CAA monitors the status of space and ground based astronomy and astrophysics and provides assessments to the National Science Foundation, NASA, and other institutions as a joint committee of the Space Studies Board and the Board on Physics and Astronomy. The overall objective of the CAA is to encourage progress in astronomy and to assist the federal government in program choice and implementation in these fields. (Mission statement of the CAA.)

The CAA has both made broad recommendations and worked specifically with NASA to establish priorities. In their 1997 report, the CAA chose among the many options and identified four particularly important and timely priorities in space astrophysics for the early years of the coming decade. In ranked order (itself remarkably unusual even among so-called priority-setting processes) the recommended priorities were:

1. Determination of the geometry and content of the universe by measurement of the fine-scale anisotropy of the cosmic microwave background radiation;
2. Investigation of galaxies near the time of their formation at very high redshift;
3. Detection and study of planets around nearby stars; and
4. Measurement of the properties of black holes of all sizes.

The second and third priorities were given virtually the same weight. Four additional scientific objectives were judged to be of high priority but nevertheless less urgent than the primary four listed above, or less achievable in terms of possible space missions. These recommended secondary objectives, unranked, are:

- Study of star formation by, for example, high-resolution far-infrared and submillimeter observations of protostars, protoplanetary disks, and outflows;
- Study of the origin and evolution of the elements;
- Resolution of the mystery of the cosmic gamma-ray bursts; and
- Determination of the amount, distribution, and nature of dark matter in the universe (A New Science Strategy for Space Astronomy and Astrophysics, Executive Summary.)

Other efforts by this committee to influence priority setting have included a letter to the National Science Foundation, sent at that agency's request, on the direction and usefulness of NSF's facility instrumentation program (FIP). In this letter, the committee reaffirms its support for the NSF FIP program, but suggests program changes in the length of telescope time available to the public and other modifications. Other committee letters have been sent on Antarctic astronomy, cooperation with the European Space Agency, and on the Cassini Saturn Probe. (NAS website)

4. CRITIQUES AND SUGGESTIONS PRESENTED IN THE LITERATURE

Critiques and suggestions in the literature on federal R&D budget coordination and priority-setting most often take the form of normative statements at a fairly high level of generality. Proposals offering procedural details on alternative mechanisms, discussing how systemic transitions might be staged or speculating on possible secondary effects from such shifts, are almost non-existent. Detailed critiques of specific methodological approaches are even more rare than pieces detailing methodologies as applied in agencies or other bodies. Most pieces tend to advocate some selective change, rather than offer an integrated design.

What follows is a review of what was found to be most relevant in answering the questions posed by the Committee. It will be noted that the literature rarely addresses these questions directly and so must be culled for passages shedding light on the issues. It will also be quite clear that there is a fine line between critiques of current methodologies and implicit suggestions for making improvements to existing process.

CRITIQUES OF CURRENTLY EMPLOYED METHODOLOGY

Perhaps the most frequent critique addresses a perceived lack of clear methodology for priority setting and coordination. This is implicit in the first Clinton administration statement of policy in this area. *Science in the National Interest* tasked federal agencies as follows:

Each agency that depends on or contributes to our science and technology base will, with involvement of the scientific community, delineate its fundamental research and education missions with respect to the national goals; develop long-range plans for its fundamental science, mathematics, and engineering investment; and develop measures to evaluate its contributions. (Clinton and Gore, 1994; p. 19)

With the enactment of the Government Performance and Results Act (GPRA) in 1993, this implicit critique has begun to be addressed. Yet, a further implicit critique may be found in the actions of the House Science Committee which held hearings in 1996 and 1997 on implementation in the civilian science agencies and announced, in 1997, that this would be a major oversight target. Several committees asked agencies to link FY1999 and FY2000 budget requests to goals expressed in their strategic and performance plans. (CRS Reports 97-70, 97-382, RS20257, and 98-224)

A major argument in the 1995 NRC report (commonly referred to as the "Press" Report) is the need for some form of "comprehensive" and "coherent" coordination of federally financed research. (NAS, 1995) The NSB concluded that such comprehensive coordination of federally financed research "could assist the President and Congress by providing a valuable addition to and improvement over the processes presently in place. However, implementation of such a policy would involve the difficult task of developing acceptable procedures....This timely and critical but highly controversial proposal merits careful attention at this time." (NSB 1997)

One implicit critique would appear to be pulling in the opposite reaction. This would advocate a shift from the current basic budgetary stance where R&D expenditures are set de facto as a fixed proportion of the federal budget to one where the goal of federal R&D funds is explicitly to support the conduct science, not to achieve some

broader ends. (Lederman 1991, p. 18) The proposal, certainly part of a nuanced and sophisticated argument, would suggest a less instrumental orientation toward science as a means to address specific ends and more of a stance that viewed research as being ultimately useful but worthy of support in itself.

ADVANTAGES/DISADVANTAGES OF DIFFERENT METHODOLOGIES

Aspects of the literature that explicitly weigh the benefits and drawbacks of different methodological approaches would include the Robinson critique of the Press report. His argument against a more coherent and integrated federal S&T budget is that:

- trade-offs should not be made between different categories of federal S&T investment, but in as much as most such research is performed to advance the mission of a government department or agency, the tradeoff should be made at the agency level between S&T investment and other expenditures of the agency conducting the S&T;
- the Press report underestimates the value of the mechanisms already in place that develop coherence in S&T activities in specific areas and especially the role of the NSTC;
- where cross-cuts need to be made for coordination purposes, NSTC can consider trade-offs between compatible activities and not need to engage in the "overly comprehensive process" proposed by the Press panel. (Robinson, 1997)

This all having been said, the final point (although whether intended as a policy prescription or a *reductio ad absurdum* argument is unclear) is that to truly achieve the balance of S&T resources in one area with those in another would require the creation of one department in agency in which all the activities are being carried out. (pp. 218-220)

A consultant report to the Carnegie Commission (Shapley, 1992) notes that the budget process "cannot be expected to provide a method or even an analytic framework for setting the major priorities [on R&D] in the budget," because the goals of federal programs are simply too diverse and lack common criteria for setting priorities among the nation's goals (p. 40). As a bottom line, after weighing various criticisms and suggestions, Shapely finds the treatment of R&D has both strengths and weaknesses as played out in the current form of the budget process. Its strengths include a) wide recognition of the need for and importance of R&D; b) the acceptance of a major federal role in support of R&D; and c) the fact that [writing in 1991] "no one is really against it."

However, weaknesses exist as well. R&D budget submissions tend to be treated on a "level of effort" basis in as much as it is too difficult to budget by individual projects. These are "very hard to defend" and mask indivisibilities and rigidities that might cause cuts to have a more than proportionate effect and so, in effect, change priority decisions. There is also an inherent weakness in many justifications offered in support of R&D budgets. Precisely because of difficulties in making causal arguments and tracking benefits directly back to research outcomes, it is difficult to persuade that a given investment in R&D should occur this year rather than next. And finally, there is a "vulnerability that arises from the "expanding universe" nature of R&D budgets" i.e., "the constant

expansion of areas of important scientific research and opportunities for technological advances conspires with other factors to make increases in R&D budgets necessary year after year." (pp. 62-67)

Another view suggests the present system for budgeting has a subtle affect on priority allocation among disciplines. In the case of several disciplines, their fortunes are inordinately tied to the missions of particular agencies. These disciplines are heavily affected by changes in agency programs leading to severe *post facto* cuts in the funding to these fields. In this view, there is need for explicit determination of what levels of funding would be appropriate on a field by field basis with the larger national interest in view. Principal policymaking bodies need to make adjustments to the funding portfolio when there appears to be a serious shortfall in desirable investment. (Merrill and McGeary, 1999)

EVIDENCE OF USE OF METHODOLOGIES

As noted above, most critiques are concerned with higher aggregate concepts and are less likely to deal with actual methods for assigning priority or coordinating budgets. Instances in the literature indicating the extent to which different methods are used have already been presented above in the discussion of methods and models employed in the research portfolio managing agencies.

SUGGESTED APPROACHES TO IMPROVING PROCESS

The literature presents many alternatives to the present processes of priority setting and budgetary coordination. The suggestions tend to fall into one of three areas: alternative weightings or other means for deriving priorities for federal research support from larger national goals; suggestions for alternative mechanisms for budget coordination and ensuring allocation of funds in accord with priorities within existing institutions; and elements of a design leading to changes in those institutional structures themselves.

Priorities for Allocation

In the first area, there are calls to make more clear the *raison d'être* for federal R&D support. Some themes recur and amount to suggestions for specific priority choices. One study, for example, advocates generating a formal annual comprehensive Federal Sustainable S&T budget. The budget would provide a ranking of research areas in relation to importance for sustainable development as part of a coordinated cross-agency and cross-branch allocation effort. (NAS, 1995)

Sustainability is not the only issue to have been elevated to a prominent place in S&T decisionmaking at the national level. More broadly, there have been calls to link the allocation of research funds to the quest for addressing societal goals. (Carnegie, 1992) The comprehensive OTA study on alternatives points out that whatever criteria chosen should be made explicit to ease actual processes of selection and allocation. (OTA, 1991) Further, there are no true means for looking at the federal research portfolio in its totality to assess progress toward goals and

that the selection criteria most commonly applied, scientific merit and mission relevance, "are in practice coarse filters." (p. 11) This study also provides an adapted list of more fully specified evaluation for selecting among competing initiatives:

Scientific Merit:

1. Scientific objective and significance
2. Breadth of interest
3. Potential for new discoveries and understanding
4. Uniqueness

Social Benefits:

1. Contribution to scientific awareness or improvement of the human condition
2. Contribution to international understanding
3. Contribution to national pride and prestige

Programmatic Concerns:

1. Feasibility and readiness
2. Scientific logistics and infrastructure
3. Community commitment and readiness
4. Institutional implications
5. International involvement
6. Cost of proposed initiative (Dutton and Crowe, 1988 as in OTA, 1991, p. 141)

In addressing these issues, the foundation document of the Clinton Administration's science policy calls not only for a re-shaping of that policy to sustain U.S. scientific preeminence but also to direct science toward advancing the core elements of the national interest: health, prosperity, national security, environmental responsibility, and improved quality of life. (Clinton and Gore, 1994) As noted previously, NSTC is to play a primary role in ensuring that this cross-product yields a research portfolio in conformity with these goals. Yet, a Council on Competitiveness report still underscores a need for the U.S. to establish a national consensus on R&D goals. (Council on Competitiveness, 1996)

In addition to priorities set by issue area, there are also calls to do so by stage of the research and innovation process or other criteria. For example, calls to use federal research funding to strengthen education and human resources or to focus on regional and institutional capacity would fall in this category. (OTA, 1991). Many of these also are echoed in *Science in the National Interest*. (See, e.g., pp. 23, 27) They are formalized in such programs as SBIR, EPSCOR, and less formally by earmarking or other sectoral allocations. Similarly, there are also suggestions to shift the focus of funding in the federal R&D portfolio dramatically in direction of support to basic research. (CRS, 1995) But, on the other hand, the Council on Competitiveness states that parsing the federal R&D budget by the old definitions of basic and applied research has proved politically ineffective. It calls on the U.S. to "adopt a new and more up-to-date vocabulary, one that accounts for changing calculations of R&D risk and relevance over short-, medium, and long-term horizons." (Council on Competitiveness, 1996)

Mechanisms for Allocation

The second major group of alternatives does not address itself so much to the priorities for allocation as to the mechanisms by which allocations should occur. The common characteristic of this group of suggestions is that they would preserve existing institutions for federal research portfolio management. However, the means used by these institutions would pursue their efforts would change.

As noted above, alternative models for allocation already exist at different agencies. Peer review is the standby for allocation and selection at both NIH and NSF. The strong program manager model is the hallmark of DARPA. NASA's formal apparatus exists as a mixed case (as do they all, to one degree or another). Models already in existence in federal agencies may be applied to other federal agencies in furtherance of particular goals or program elements. The recent report by the House Science Committee on science policy suggests, "other federal agencies should consider increasing the use of this method [peer-reviewed research grants] of supporting and encouraging [investigator-driven, non-commercial] research." (U.S. Congress, 1998; p. 16)

Several suggestions have been made for fundamental changes in allocation methods. Some entail crafting methodologies based upon different theoretical bases than ones now employed. As an example, one proposal would utilize an options approach to R&D funding where the portfolio is constantly updated and balanced for risk and takes advantage of increased information availability over time. It is not clear that such an approach is not already employed informally (e.g., by DARPA) but this suggestion would formalize the approach and make it a primary allocation mechanism across federal science-funding agencies. (Vonortas, 1999)

Identifying Areas of Special Interest

Many contributions to the literature view the system as it currently operates as largely successful for the bulk of research needs and requiring no fundamental change. However, within a pluralistic, multi-agency budgeting approach, areas requiring special attention can be identified. In the formulation by the Presidents of the National Academies, these latter would include initiatives contributing to the science base, especially in modifying its direction of development along several axes; S&T initiatives tied to major presidential or congressional objectives; and major (for which read "big science") S&T initiatives slated for rapid growth or deceleration. These last require extra attention owing to their large potential for spillover effects on other agencies. (NAS/NAE/IOM, 1988)

The question of how the sorting of priorities and subsequent allocation is actually to occur is frequently left unstated. A background paper prepared for the National Academy of Sciences synthesizes several studies. Going back to the vision of Vannevar Bush, "criteria for support were inherently left to internal sorting within the administrative structure he envisioned....Most other reports have provided process suggestions for balancing priorities, but have implicitly left the criteria to be used to those engaged in the process." (Cook-Degan, p. 23) The report notes that both the Carnegie Commission and OTA [in the studies cited above] suggested House hearings, for example. But it goes on to state that "the most promising leads for crafting criteria of use[in crafting criteria for priority] may not come from reports that have not [sic] been policy reports covering all R&D...but instead from

approaches taken within fields." He cites the example of the 1972 NRC report *Physics in Perspective* which discusses criteria internal to fields within physics and another set external to science that can help assess their relative priority. "The committee came up with a set of 18 questions, and then used the criteria on subfields within physics and found a surprising degree of consensus."

Finally, in this connection several reports point up, on the one hand, the paucity of data gathering and, on the other, the necessity for establishing a database on the entirety of the federal R&D budget for the purposes of priority setting, coordination, and evaluation. (OTA, 1991; Shapley, 1992)

Modifying the Priority-Setting Institutions

The last category of suggestion and alternatives to be found in the literature are those which address themselves to and advocate modification of the institutions of federal research portfolio management themselves.

Perhaps the most frequent observation in the literature we reviewed was that the federal R&D portfolio is only a *post facto* accounting concept. It is, by default, the aggregation of individual mission agency portfolios but is in no sense managed as a unified portfolio. Several studies advocate a greater role for NSTC, OSTP, and/or OMB in setting portfolio guidelines at a higher level than that of the funding agencies as well as actively monitoring fulfillment. (see, e.g. Carnegie, 1992) Formally speaking these are institutions already in existence. Yet, as a practical matter this would constitute a fundamental redrafting of the role of these agencies and the nature of their interactions with the rest of the federal research portfolio management structure.

A number of reports have called for improved scientific coordination across the agencies. Willis Shapley makes three recommendations: 1) establish a comprehensive, comparable data base on R&D budgets; 2) create a detailed "directory" report that could provide comprehensive information on what agencies are engaged in what kinds of R&D; and 3) prepare a report on "R&D in the Budget" each year. (Shapley, 1992)

Alongside suggestions for different goals stands the recommendation that a new institutional structure for setting such goals be created. One paper advocates establishing a non-governmental National Forum on S&T to set the goals for the entire establishment. Upon its creation, such a body would first identify the *de facto* goals that are presently operative based on past budgets. It would then develop the means for defining goals for the system of federally funded research within the context of broader societal or governmental goals. (Carnegie, 1992) Another suggestion along these lines would be for such a body to define what the essential elements in the federal R&D portfolio must be and suggest ways in which the portfolio's composition may be more readily adapted to changing national circumstances. (Hill, 1995)

There are also suggestions whose effect would be to provide a variation on the Vannevar Bush vision of a single National Research Foundation. Given the greater mission orientation and institutionalization of federal decisionmaking that characterizes the present compared with Bush's time, the proposal is less for such an agency than to provide centrality by actually formulating and passing through Congress a Federal S&T Budget. Rather than existing as a *post hoc* accounting concept that is the construct of a bottom up process, such a budget would be designed as an instrument not so much for allocation as for the setting of allocative priorities in a top down manner.

(NAS, 1995) This proposal, for good or ill, would make more visible the funding activities supporting federal efforts in supporting S&T as well as to make clearer the tradeoffs required to balance the public's interest in this area of policy. In a further discussion of this idea, Press (1997) makes the points that the FS&T budget would be focused on more narrowly defined activities than are presently referred to as "R&D" so that the principal recipients of federal funding would shift from industrial contractors to federal laboratories and universities. It would work by forcing trade-offs by "transfer of funds from poorly evaluated or obsolete programs to those of higher quality or those more responsive to social and economic exigencies...The FS&T budget is an instrument that looks at the real R&D pool, moves funds around within it, and keeps a running score of what's happening." (p. 175) The main purpose is to protect the worthy programs from being "picked off [by] mindless decisions."

Arguments for Maintaining the Current Pluralistic System

Although a number of reports and papers recommend alternatives to the current system of budgeting and priority setting, not all of them call for change. Just as Willis Shapley argued in "The Budget Process and R&D", cited above, that priorities must be set within the political process, Christopher Hill, David Robinson and Albert Teich make similar arguments in other publications. Hill notes that "federal R&D spending levels are determined in a "profoundly political process, representing a balance among competing interests, not only with respect to R&D, but also with respect to all other claims on the federal treasury (Hill, 1995, p. 5), and he asserts that this process serves science fairly well. Even the National Academy of Sciences, in a 1988 report, notes that the pluralistic approach to budgeting has been a strength of the U.S. system. (NAS reports in the 1990s take a different view.)

In a paper written in response to the NAS report Allocating Federal Funds for Science and Technology, Robinson says "...trade-offs should not be made between different categories of FS&T investment, but between S&T investment and other expenditures of the agency conducting S&T..." just as it is now. Moreover, Robinson argues that the Press panel underestimates the value of the current mechanisms to develop a coherent S&T program. The NSTC "crosscuts" have improved the efficiency of the process. Similarly, Teich notes that priority-setting is an integral part of the regular budget process and "not something done internally by the scientific community and then handed over to government..." Moreover, Teich notes that which groups should speak for science is not at all clear:

Advocates of priority-setting have suggested that it is important for the scientific community to present a unified appearance to the outside world. But who can speak authoritatively on behalf of the scientific community? A committee of the National Academy of Sciences? The scientific associations? (If so, which?) OSTP? This is not a trivial matter. Whichever body conducts the priority-setting exercise has to be broadly accepted in all fields of science and legitimate and powerful enough to stand behind what are bound to be unpopular choices (Teich, 1991, p. 43).

These and several others, including Hill (1995) suggest that the current process of trade-offs and political decisionmaking, influenced by advocates of science, actually works fairly well and meets the needs of science for adequate funding.

5. OBSERVATIONS AND SUGGESTIONS

In the preceding pages this report has presented an analytical review of the literature pertaining to several issue areas touching upon federal R&D budget priority setting and coordination across fields of science. To the extent that the literature spoke with a clear voice, we have sought to present that voice. When the voice was more subdued or oblique, we attempted to present the main lines of discourse in a manner that would illuminate the issues of interest to NSB. Synopses of the literature provided in this document had the intention of capturing the essence of what these voices were conveying. Where the voice was silent, we have noted its absence.

In what follows, we offer several insights drawn by the research team during the course of its endeavors. The spirit which informs this effort is less to provide a self-contained collation and synthesis of the literature than to offer propositions for discussion and further refinement through Committee interactions and between the Committee and the NSB staff.

Overall Assessment of the Literature

The literature is skewed toward the prescriptive rather than the descriptive and tends to take a broad view rather than examine operations at the agency level. Thus, few formal models of current priority setting, allocation, and coordination have been identified.

The literature as it stands falls into three categories:

- A robust literature offering advice to government on how best to set goals and allocate funds, both as a national endeavor and across governmental agencies;
- A smaller but growing base of procedural publications describing how the process of research and development (R&D) allocation should be done within an agency or a discipline;
- A few examples of how the process actually takes place within the government.

There is little in the literature describing efforts at coordination other than those of the NSTC, either among scientific programs across agencies, or, efforts to coordinate programmatic activities among different fields of science.

More attention is paid to goal setting than coordination. Recommendations fall into three broad categories:

- A shift to a national-goals approach, tying the priority setting process to national goals;
- A scientific-goals approach advocating cross-cut assessments of existing spending in areas of science and realignment of budgets, if needed, to better meet the needs of scientific advancement; and
- Fine-tuning of the existing complex, political process.
- There is a richer discussion on goals and priority setting within the executive branch than within Congress. Qualitative discussions of how, or even whether, Congress decides between funding options

for different areas of science, different federal R&D programs, or different research project areas are comparatively rare.

- Agencies differ in setting priorities for science based on whether they have a scientific or mission orientation. Most agencies now use some combination of an outreach or advisory -approach to priority setting by gathering in views from various stakeholders, combined with a strategic planning approach, setting strategic goals and seeking to implement them. How these two functions interact within the agencies to affect priorities is not detailed in the literature.

Detailed Consideration of Key Gaps in the Literature

- There is relatively little detail about the actual operations of the NSTC in coordinating federal R&D policy, planning, and budgets. The literature cites the role of the NSTC in coordinating larger initiatives and crosscuts, although the actual importance of the NSTC committees versus decisions by the OMB budget examiners or Assistant Directors is not detailed. Likewise there is little description of the NSTC role, if any, in determining funding in agency core R&D programs not connected to a larger budget priority or "crosscut."
- There is little to no description of the process that takes place within the Executive Branch in the 11 months leading up to the release and explanation of the President's budget. The development of agency budgets can be complicated, especially in agencies with both R&D and operational programs (DOE, NOAA, USDA, etc.). The struggle within agencies for resources in the period prior to the submission of the proposed budget to OMB in September is nowhere in the literature. Yet this process sets the terms of negotiations between OMB and the agencies for the rest of the year.
- Likewise, the give and take between OMB and the agencies prior to the agencies being "locked out" of the budget in December is not described. There is no mention of how the individual divisions of OMB make decisions, set priorities, or allocate funding. To the point of this paper, there is no mention made how, or even whether, there are any attempts made at OMB to coordinate R&D policy, planning, or budgets between agencies and departments.
- The readjustment of the budget that occurs after the agency "lock out" in December, and when final Presidential priorities are set, prior to the budget being final in January, are not described in the literature. Yet many recent significant R&D budget and policy decisions have been made in this final administration budget deliberation.
- Likewise, there is little description of the various ways in which Congressional committees influence the direction and conduct of federal R&D through a number of informal means. The language contained in appropriations bill reports carries the force of law and it is in those reports that many qualitative decisions are made that influence an agency's priorities. Even telephone communications between key appropriations staffers and agency administrators have resulted in significant shifts of funding or R&D program direction. Location-specific earmarks are only one form of this

Congressional communication. The initiation of a major federal R&D effort on breast cancer at DOD was the result of Congressional intervention in the priority and funding process. Most of these decisions are made without reference to what deliberative process that was used to make them and scholarly documentation is rare.

- There is no published explanation for the current balance or trends among research accounts (shown most recently in the paper by Merrill and McGeary). Major decisions are being made outside of any formally described R&D policy, planning, or funding process. The chart in Merrill and McGeary on funding trends by discipline is not accompanied by any explanation of how Congress or the agencies involved arrived at these decisions or whether this was even the result of any premeditated process.
- Coordinate with the above point, as rare as detailed descriptions of the formal priority setting mechanisms of federal R&D managing agencies are, rarer still are documents elaborating on either the details of these procedures in practice or the degree to which that practice actually corresponds to, or deviates from, the formal procedures.

Data Issues

- Data on the contents of the federal R&D portfolio contain either highly aggregated budget information or disaggregated project descriptions. There is considerable difficulty in finding common bases for combining data collected by different agencies.
- A considerable problem when concerning existing databases is mixed definitions. The terms "R&D" and "S&T" are often used as synonyms. Not only do these terms carry different meanings in the defense and civilian agencies, S&T carries multiple meanings. Lack of awareness of this continually impedes efforts to improve planning, management, and coordination of federal science activities.

Uniqueness of the R&D Planning Problem

The coordination of federal R&D functions has been the subject of considerable attention and deliberation. These efforts began with the Science Policy Act of 1976, have found new form with the development of instruments such as the NSTC, and certainly continue on through to the NSB's own inquiry today. It might be worth noting explicitly just how remarkable both this effort and the area of federal activity it seeks to address truly are. One is hard pressed to name other vital federal government functions in the discretionary part of the budget that cross so many Executive agency and Congressional committee lines. It is hard to think of any parallel federal activity that has such importance and such a broad involvement of so many agencies. To be sure, there are programs seeking to provide public assistance, income support, and transfer payments spread about the federal structure, but those are for the most part mandatory programs. Other vital government functions are contained in single agencies: education finally was given its own department, as were health, housing, veteran affairs, etc. There may be parallels in such fields as natural resource planning or issues related to the use of nuclear power, but they involve only a few

agencies. And if this were not enough, the R&D planning problem needs not only to be funded, managed, and administered across the government, it needs to be applied across quite disparate fields of science.

The discussion of coordination issues presented in this literature review points up the unique nature of the R&D coordination and priority setting problem. What does this imply for the NSB's explorations and deliberations? In essence, if it is true that there are no other federal activities that have to coordinate their functions across so many agencies, any coordination effort will to a large extent need to make its own way without other successful models of coordination to borrow from. This certainly suggests the value of beginning with first principles in considering what may be desired in this area and what efforts may be needed to bring it about.

Alternative Approaches to Management

The alternative approaches for managing the federal research enterprise we have detected in the literature fall into three areas: 1) alternative readings of what are the appropriate *goals* federal research support should seek to fulfill; 2) suggestions for alternative *mechanisms* for allocation of funds within the existing institutions for managing the federal research portfolio; and 3) elements for a design leading in whole or in part to changes in those *institutional structures* themselves. The two consistent threads, present in varying degrees, are a desire to establish priorities and to do so in a coordinated fashion.

This is understandable. A frequent theme of the literature is that the federal R&D portfolio is only a *post facto* accounting concept. It is, by default, the aggregation of individual mission agency portfolios but is in no sense managed *ex ante* as a unified portfolio. Several studies advocate a greater role for the NSTC, OSTP, and/or OMB in setting portfolio guidelines at a higher level than that of the funding agencies as well as actively monitoring fulfillment. A necessary first step to effective prioritization, in other words, is to achieve coordination. Yet, such a quest may prove to be chimerical.

As we have suggested, "coordination" may refer to hierarchical synchronization as a means to ensure that larger goals are being met through the smaller-scale decisions over priority and allocation. Alternatively, the term refers to cross-cutting coordination to ascertain that the actions of individual agencies do not excessively duplicate or pre-empt those of other agencies. The two themes are highly intertwined.

Is Coordination Really Deficient?

A persistent assumption in the literature is that greater coordination is desirable and can be attained by setting high level goals and then proceeding to lower levels of decisionmaking authority. This seems problematic on two counts. First, decision making in this area is embedded in existing institutions and political processes. Setting high-level goals and then rigorously enforcing them as the means for crafting priorities and making allocations on lower levels would, in effect, stand the present system on its head.

Second, such an approach may not accord with the evolving pattern for the commerce of ideas and knowledge management. Modern science is increasingly cross-disciplinary, with major discovery taking place at

the interstices of traditional disciplinary categories. Contributing to this trend are increased globalization of effort with geographically dispersed working teams crossing geographic boundaries and an ever denser connectivity of information and ideas.

This is not to suggest that prioritization or coordination are undesirable or that gaining a measure of control is impossible. Rather, it is to suggest we think about the following questions:

1. What do we mean by the terms "priority" and "coordination"?
2. What do we hope to achieve and how will we improve the public's lot through prioritization and coordination?
3. What alternative models, not necessarily predicated upon traditional views of either the science process or its effect on the larger society, need we consider to best develop means for achieving a true ability to set priority and the level of coordination we desire?

SPECIAL ISSUES SECTION 1. THE ISSUE OF DEFINITIONS: "R&D" VERSUS "S&T" AND GOVERNMENT DATA SOURCES

The National Science Board has formally recognized the importance of explicitly addressing the definitions of "research" and "development" and has stated that "considerable confusion has been created by imprecise and sometimes improper use of the term R&D. The Board feels it is important to clarify this issue." (NSB, 1997). The discussion then considers the nature of the two distinct but interrelated activities from a substantive perspective. However, the problem alluded to by NSB is even more general and subtle than this document would suggest.

In particular, although the terms "science and technology" (S&T) and "research and development" (R&D) are often used interchangeably, they have very different meanings in the context of the federal government. Specifically, there is one overarching definition of R&D used by all federal agencies. There are at least two conflicting meanings of S&T, however, neither of which is synonymous with R&D. A lack of awareness of these differences has continually impeded efforts to plan, manage, and coordinate federal R&D activities. It has also had an effect on the allocation of federal R&D resources. In the literature examined in this project, numerous examples were found of how the different and conflicting meanings attached to these terms by various parts of the federal government have also made it difficult to set priorities and coordinate activities among federal agencies.

WHAT IS "RESEARCH AND DEVELOPMENT" WITHIN THE FEDERAL GOVERNMENT?

R&D is a budget category that is defined by the Office of Management and Budget (OMB) in Section 25 of Circular A-11. The overall purpose of this circular is to provide detailed instructions and guidance to federal agencies regarding the preparation and submission of their annual budget requests, as well as their strategic, performance, and capital asset plans. The specific purpose of Section 25 is to designate the character of all federal funds by noting if they are purchasing an investment whose benefit will not be realized for some time or a non-investment whose benefit is more immediate. Because R&D activities constitute the primary long-term investment of the federal government (education and training is number two), R&D is separately tracked in the federal budget. As noted in the left side of the chart below, the OMB definition of R&D is composed of five parts: Basic Research, Applied Research, Development, R&D Equipment, and R&D Facilities. The first three of these categories are collectively referred to as the "Conduct of R&D."

As noted in the right side of Table 2.1 below, the Department of Defense (DOD) alone among the federal agencies has refined the government-wide OMB definition by sub-dividing the Development category to distinguish among the many R&D activities that tend to be unique to DOD. DOD then takes one of these sub-categories of Development and groups it with Basic Research and Applied Research and collectively refers to these three activities as S&T. In so doing, DOD officially designates S&T as a sub-set of R&D for the military activities of the federal government.

Table SS1.1 Government-Wide and DOD Definitions of R&D

Definition of R&D					
Government-Wide			DOD-Unique*		
OMB Circular No. A-11 (1998)			DOD Financial Management Regulation (Volume 2B, Chapter 5)		
	Basic Research	Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and or observable facts without specific applications towards processes or products in mind.		Basic Research (6.1)	Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and or observable facts without specific applications towards processes or products in mind.
	Applied Research	Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.		Applied Research (6.2)	Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.
	Development	Systematic application of knowledge toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.		Advanced Technology Development (6.3)	includes all efforts that have moved into the development and integration of hardware for field experiments and tests.
				Demonstration and Validation (6.4)	includes all efforts necessary to evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost reduction potential of advanced technology.
				Engineering and Manufacturing Development (6.5)	includes those projects in engineering and manufacturing development for Service use but which have not received approval for full-rate production.
				RDT&E Management Support (6.6)	includes R&D efforts directed toward support of installations or operations required for general R&D use. Included would be test ranges, military construction, maintenance support of laboratories, operations and maintenance of test aircraft and ships, and studies and analyses in support of R&D program.
				Operational System Development (6.7)	includes those development projects in support of development acquisition programs or upgrades still in engineering and manufacturing development, but which have received Defense Acquisition Board (DAB) or other approval for production, or production funds have been included in the DoD budget submission for the budget or subsequent fiscal year.
					Developmental Test & Evaluation
				Operational Test & Evaluation	Efforts associated with engineering or support activities to determine the acceptability of a system, subsystem, or component.
R&D Equipment	The acquisition of major equipment for R&D. Includes expendable or moveable equipment (e.g., spectrometers, microscopes) and office furniture and equipment. Routine purchases of ordinary office equipment or furniture and fixtures are normally excluded.		No separate definition	Major equipment dollars are mixed with the dollars for the "Conduct of R&D" and carried in the RDT&E accounts (i.e., 6.1 through 6.7) listed above. In FY 1998, DOD requested a total of \$68M for major R&D equipment.	
R&D Facilities	The construction and rehabilitation of R&D facilities. Includes the acquisition, design, and construction of, or major repairs or alterations to all physical facilities for use in R&D activities. Facilities include land, buildings, and fixed capital equipment, regardless of whether the facilities are to be used by the Government or by a private organization, and regardless of where title to the property may rest. Includes such fixed facilities as reactors, wind tunnels, and particle reactors. Excludes movable R&D equipment.		No separate definition	In FY 1998, close to 90% of the \$67M requested by DOD for R&D Facilities was carried separately in Military Construction accounts. The rest were included in the costs of major development programs and are mixed with the dollars for the "Conduct of R&D" carried in the RDT&E accounts (i.e., 6.1 through 6.7) listed above.	
* Does not pertain to the Corps of Engineers.					
** Includes administrative expenses. Excludes routine product testing, quality control, mapping, collection of general-purpose statistics, experimental production, routine monitoring and evaluation of an operational program, and the training of scientific and technical personnel.					
*** Includes costs of laboratory personnel, either in-house or contractor operated.					

WHAT IS "SCIENCE AND TECHNOLOGY " WITHIN THE FEDERAL GOVERNMENT?

Parallel to the designation of specific federal activities as R&D there is a simultaneous labeling of these and all other federal activities as to their general purpose (i.e., mission) or function. Listed in Table 2.2 below are the substantive functions among which all federal activities are allocated.

Table SS1.2 Functional Designations of R&D Activities

Functional Designations of R&D Activities*		
Function Code	Primary Purpose of Activity (Function)	Agencies Funding R&D in Area
050	National Defense	DOD (Military), DOE
150	International Affairs	AID, ACDA
250	General Science, Space and Technology	DOE, NASA, NSF
270	Energy	DOE, TVA, NRC
300	Natural Resources and Environment	DOD (Civilian), DOI, USDA, DOC, DOT, EPA, MMC
350	Agriculture	USDA
370	Commerce & Housing Credit	DOC, USPS
400	Transportation	NASA, DOT
450	Community & Regional Development	DOC, TVA, HUD
500	Educational, Training, Employment & Social Services	HHS, DED, DOL, SMITH
550	Health	DOD (Military), HHS, DOL
570	Medicare	HHS
600	Income Security	DOL, SSA
650	Social Security	SSA
700	Veterans Benefits & Services	DVA
750	Administration of Justice	DOJ, TREA
800	General Government	TREA
* The Budget Function is a classification made without regard to agency or organizational distinction that best defines the activity's most important purpose in terms of addressing one of 17 national needs. These national needs are broad areas used to provide a coherent and comprehensive basis for analyzing and understanding the federal budget. A function may be divided into two or more subfunctions, depending upon the complexity of the national need addressed by the function. (<i>A Glossary of Terms Used in the Federal Budget Process</i> , GAO 1993)		

As is clear in the chart above, R&D activities are found in every functional category in the federal budget. Of particular interest are the R&D activities in Function 250 – General Science, Space and Technology. This functional category encompasses the National Science Foundation (NSF) and a large portion of the Department of Energy (DOE), in addition to the National Aeronautics and Space Administration (NASA). As a result, all of the activities in these functional categories, most especially those of NSF and much of DOE, are officially labeled as S&T activities. Only a part of the activities in each of these functional categories, however, are categorized as R&D. Consequently, for these agencies, R&D is a sub-set of S&T.

Table SS1.3 R&D vs. S&T by Agency and Function

R&D vs. S&T by Agency and Function (All dollars are Budget Authority in Millions for FY 1998)					
Agency*	Main Budget Function Code	National Need/Goal (Sub-Function Category)	Total Dollars in Category	R&D Dollars in Category	S&T Dollars in Category
DOD	050	Department of Defense - Military	256,333	37,390	7,663
	550	Health research & training	177	177	177
	300	Water resources**	4,189	39	?
HHS	500	Social services	13,413	25	?
	550	Health care services	114,262	197	?
	550	Health research & training	14,310	13,387	?
	550	Consumer & occupational health & safety	926	159	?
	570	Medicare	284,710	50	?
NASA	250	Space flight research & support activities	12,312	6,426	12,312
	400	Air transportation	1,326	1,326	?
DOE	050	Atomic energy defense activities	11,523	3,012	?
	250	General science & basic research	2,236	2,228	2,236
	270	Energy supply	2,353	881	?
	270	Energy conservation	589	356	?
NSF	250	General science & basic research	3,407	2,583	3,407
USDA	300	Conservation & land management	5,986	191	?
	350	Agricultural research & service	3,005	1,356	?
DOC	300	Other natural resources	2,052	574	?
	370	Other advancement & regulation of commerce	1,815	504	?
	450	Area & regional development	367	1	?
DOT	300	Pollution control & abatement	131	4	?
	400	Ground transportation	28,683	387	?
	400	Air transportation	9,161	242	?
	400	Water transportation	3,710	16	?
	400	Other transportation	185	9	?
EPA	300	Pollution control & abatement	7,611	637	?
DOI	300	Water resources	994	10	?
	300	Conservation & land management	1,574	36	?
	300	Recreational resources	3,919	171	?
	300	Other natural resources	767	403	?
DVA	700	Hospital & medical care for veterans	18,541	604	?
	700	Other veterans benefits & services	942	4	?
DED	500	Elementary, secondary & vocational education	18,236	57	?
	500	Higher education	13,074	10	?
	500	Research & general education aids	772	93	?
	500	Social services	2,592	49	?
AID	150	International development & humanitarian assistance	3,690	150	?
	150	International security assistance	na	21	?
SMITH	500	Research & general education aids	490	146	?
DOL	500	Training & employment	8,375	65	?
	550	Consumer & occupational health & safety	539	5	?
	600	General retirement & disability insurance (non-SS)	1,246	1	?
DOJ	750	Federal law enforcement	8,330	3	?
	750	Criminal justice assistance	5,130	56	?
USPS	370	Postal Service	4,693	56	?
NRC	276	Energy information, policy & regulations	468	51	?
HUD	450	Community development	5,171	37	?
IVA	270	Energy supply	5,367	35	?
	450	Area & regional development	70	2	?
SSA	600	Other income security	28,150	17	?
	650	Social Security	390,999	1	?
TREA	750	Federal law enforcement	3,722	11	?
	800	Central fiscal operations	8,710	2	?
ACDA	150	Conduct of foreign affairs	43	1	?
MMC	300	Conservation & land management	1	>1	?
* Agencies are listed in the same order as they appear in Chart 1, in descending order according to the amount of R&D dollars each requested for FY 1998.					
** These dollars are controlled by the Corps of Engineers, an organization, that while housed in DOD, more closely resembles non-DOD agencies in terms of its organizational structure and operations.					

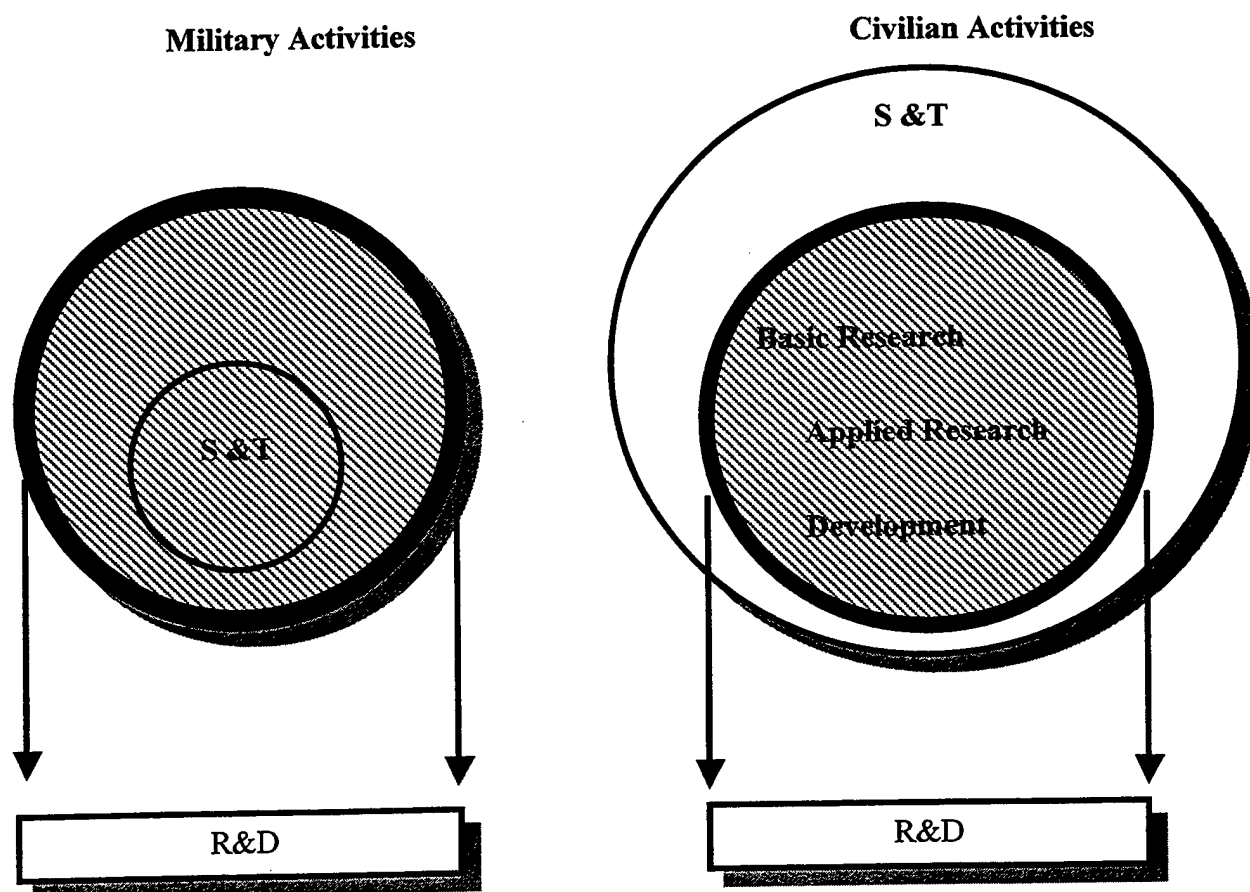
An examination of other civilian activities of the federal government reveals a similar relationship between R&D and S&T.

As illustrated in Table 2.3 above, the set of potential S&T activities in all civilian agencies of the federal government appears to be larger than the set of R&D activities in these same agencies. The magnitude of their S&T activities is hard to determine with any precision, however, as for most agencies they are not officially labeled S&T.

What is certain is that several specific activities that are widely believed to be R&D turn out instead to be S&T activities that fall outside the set of activities officially designated as R&D. The best known of these is the Manufacturing Extension Program at the Department of Commerce, which is considered by many to be R&D, even though it has never been designated as such.

CONFLICTING MODELS

Figure 2.1 R&D vs. S&T



The chart above illustrates the two conflicting models that prevail in the federal government of how R&D and S&T relate. Complicating this picture is the fact that each federal agency applies the definition of R&D differently. That is, because federal agencies have different missions, the determination of what constitutes R&D in each agency is made from a different perspective. In some instances, these differing perspectives result in agencies including different activities in the set of activities that are designated as R&D, as described in the example in the previous section. In other instances, this results in differences among agencies as to which R&D activities constitute Basic

Research, which constitute Applied Research, and which constitute Development. It is clear that activities designated as Basic Research by some agencies would likely be designated as Applied Research by other agencies and so forth. While the extent of these discrepancies has never been systematically explored across the federal government, these differences have definitely had an affect on the allocation of R&D resources, as these three categories are among the major divisions used as bases for making allocations.

IMPLICATIONS OF DEFINITIONAL DIFFERENCES FOR LITERATURE REVIEW

Executive Order 12882 described the purpose of the National Science and Technology Council (NSTC) as coordinating "S&T," while the NSTC's 1997 Annual Report describes the purpose of the council as coordinating "R&D." As demonstrated above, S&T and R&D do not refer to the same activities, so which activities are the NSTC trying to coordinate? In a further example, the charge to the RAND research team for the present project uses the terms "research" and "R&D" interchangeably. As noted in the first chart in this section, however, "research" encompasses only two (i.e., Basic Research and Applied Research) of the three categories comprising the "Conduct of R&D" and only two of the five categories comprising the entirety of federal R&D. So, what is the focus of this report? Examples such as these abound throughout the literature on federal R&D.

The collective failure to agree on the definition of critical terms and then to apply these definitions consistently has defeated and continues to defeat basic communication in the federal R&D community. Given this, it is easy to understand why coordination and priority setting efforts have also suffered.

Complicating all efforts to coordinate and set priorities for federal R&D activities is the general assumption that the R&D activities of federal agencies resemble one another. While all have been aggregated under the general umbrella of federal R&D and all involve expenditures whose benefits are long-term, the similarities diminish beyond this. For example, all of NSF's R&D activities focus exclusively on research, most especially Basic Research, to the total exclusion of Development and are conducted extramurally using grants. The nature of HHS's R&D is similar, although it does some Development and many of its R&D dollars are spent intramurally in federal laboratories. In contrast, over half of NASA's and DOD's R&D activities are Development and most are conducted extramurally using contracts. The vast majority of DOE's R&D activities are conducted extramurally using contracts, but less than a third of them are spent on Development activities. The vast majority of USDA's and DOC's R&D activities involve research, with an emphasis on Applied Research, and most are conducted intramurally in federal laboratories. Together these seven agencies annually spend approximately 95 percent of all federal R&D funds, yet clearly none of them approach R&D and its management in the same manner. Given this, it is understandable why the search for models of allocating federal R&D funds has not borne more fruit. This is especially so for models concerning the allocation of these funds by field of science and engineering as these categories have no relevance to Development activities, which account for close to 60 percent of all federal R&D activities.

DATA AND INFORMATION SOURCES SUPPORTING PRIORITY-SETTING AND COORDINATION ACROSS THE DIFFERENT FIELDS OF SCIENCE

One of the central requirements for an effective benefits assessment regime is access to databases of sponsored research which may be linked to databases of research outputs. (Kostoff, p. 33) This section examines sources of information about research and development (R&D) conducted by the federal government. It first discusses those sources containing information across agencies of the federal government and then those within specific agencies.

Databases and Information Sources Across Agencies

There are three different types of data sources containing information about R&D activities across agency lines in the federal government. Until quite recently, none of these were especially useful in supporting government-wide priority setting or coordination.

Budget Data

The first type of data source contains budget information at a highly aggregated level (that is, with no information on specific tasks or awards). The main one of these is the report prepared by the OMB for inclusion in the annual Budget of the United States Government. This report consists of a chapter in the Analytical Perspectives volume of the federal budget and has been prepared annually beginning with the FY 1996 budget. The dollar amounts it contains are "Outlays" that do not match the federal R&D baseline numbers in the main budget, which are in "Budget Authority." An overview section on R&D in the main portion of each year's budget complements this chapter.

Another source of highly aggregate information is *the Federal Funds for Research and Development* report series that has been compiled and published annually since the 1950s by the NSF. This report provides a retrospective view of federal R&D activities. The dollar amounts it presents are "Obligations," rather than "Budget Authority," so they do not match those in the official R&D baseline presented in the federal budget.

A second type of data source consists of transactional or "bookkeeping" databases, foremost of which are the Federal Assistance Awards Data System (FAADS) and the Federal Procurement Data System (FPDS). The former tracks spending on all federal grants, cooperative agreements, and other non-procurement activities, while the latter tracks spending on all contracts with a value of over \$25 thousand. Neither of these is used to track R&D activities specifically, but rather contain information on all federal activities, be they R&D or otherwise. In contrast to the data sources containing only budget information, these sources contain only disaggregated data on specific awards, none of which are connected with higher-level program or budget information.

FEDRIP

The Federal Research in Progress (FEDRIP) database attempts to present a more comprehensive picture of federal R&D activities. This database was created in 1946 as the Smithsonian Science Information Exchange and has been maintained by the National Technical Information Service (NTIS) at the Department of Commerce since 1981. Reporting to FEDRIP is voluntary, and thus it is nowhere near a complete picture of federal R&D spending or activity. FEDRIP contains no information on defense-related science R&D and covers only a portion of civilian R&D, often with quite dated records. The data in FEDRIP come primarily from several agency-specific sources -- USDA's Current Research Information System (CRIS), HHS's Computer Retrieval of Information on Scientific Projects (CRISP), NSF's Science and Technology System (STIS), and DVA's R&D Information System (RDIS) databases--that are discussed below. Several of these agency-specific databases emphasize the receipt and processing of applications for R&D funding and consequently are individually accessible in some form via the web. None is connected to the same agency's R&D budget information, however, so there is no way to relate plans to outcomes.

None of the data assembled to form FEDRIP is baselined to the federal R&D budget. As a result, users of FEDRIP cannot determine what portion of the federal R&D portfolio FEDRIP actually tracks. By carefully matching the individual records in FEDRIP to the overall contents of the federal R&D portfolio, however, it appears that FEDRIP contains data on about 20% of all federal R&D activities. Just recently, NTIS was been marked for dissolution by the Secretary of Commerce. This now appears to have passed, but the future of FEDRIP is remains uncertain.

RaDiUS

The newest information source on federal R&D spending is the RaDiUS (Research and Development in the United States) database, developed by RAND in cooperation with NSF. RaDiUS is the first information system that systematically connects the highly aggregated budget data on federal R&D with the disaggregated information on individual R&D tasks and awards to provide a complete picture of all federal R&D activities and to connect inputs with outputs. To achieve this, RaDiUS contains five interconnected levels of progressively more detailed data on federal R&D. The least detailed level of RaDiUS contains information on the 24 agencies that control and disburse all R&D dollars spent by the federal government. The amounts carried in this level of RaDiUS are identical to those presented in the federal budget for Basic Research, Applied Research, and Development. These three "stages" of R&D collectively constitute the "Conduct of R&D" and comprise the official "baseline" of the federal R&D portfolio. RaDiUS does not track funds spent on the construction and rehabilitation of federal R&D facilities or the purchase of major R&D equipment. When funds for these two activities are combined with those for the Conduct of R&D, the result is the total budget for the federal R&D enterprise.

RaDiUS harvests data on federal R&D activities from information already gathered by the federal government, even if they have not traditionally been viewed as relevant to the tracking of federal R&D

activities. For example, RaDiUS includes information from the Federal Assistance Awards Data System (FAADS) and the Federal Procurement Data System (FPDS), neither of which has ever before been used to track R&D. The harvested data have then been woven together and augmented with information from agency-specific R&D databases and information collections using common data fields and codes to form a comprehensive picture of federal R&D. RaDiUS has been used by numerous federal agencies and contractors to support R&D planning and coordination efforts, leverage R&D investments, and transfer technology.

Databases and Information Sources Within Agencies

Within agencies, there tend to be two distinct sources of data -- those containing budget and programmatic information generated for the annual budget justification process and those which track the disbursing of the agency's funds. The records in these latter systems are not uniform or consistent across agencies. In many cases these are not databases at all, but paper records. Generally, there are no direct connections between these two sources of data.

The major R&D agency-specific award/task databases include DOD's TEAMS, HHS's Computer Retrieval of Information on Scientific Projects (CRISP), NASA's FAC/507s, DOE's R&D Tracking System (created at DOE's request by RAND), USDA's Current Research Information System (CRIS), NSF's Science and Technology System (STIS), and Department of Veterans' Affairs VA's R&D Information System (RDIS) databases.

Some of these databases are used within agencies to help interested parties learn more about on-going R&D efforts to reduce duplication and encourage coordination of R&D activities. Given the lack of connection to agency budgets and program plans, it is unlikely that these databases are widely used to allocate funds or coordinate R&D activities at an aggregate level. Most of these agency-specific R&D databases are accessible to the general public in some manner via the web, while others have highly restricted access.

Tables SS1.4- SS1.6 presents a list of federal data sources containing information on science funding and activities. None of these sources, however, is devoted exclusively to science or "S&T" activities, which are virtually impossible to track given existing information. Furthermore, the relationship between the terms "R&D" and "S&T" is problematic. Although "R&D" and "S&T" are often used as synonyms, they carry different meanings in the defense and civilian agencies, and the term "S&T" itself carries multiple meanings. Lack of awareness of this fact continually impedes efforts to improve planning, management, and coordination of federal science activities.

Table SS1.4
Data Sources on Federal Science Activity

Government-wide Data Sources	Description	Useful for Priority-Setting, Coordination, or Budget Allocation?
President's Budget (OMB/MAX System) (Government-Wide Data System)		No
Catalog Of Federal Domestic Assistance (CFDA) (Government-Wide Data System)	A public information source advertising grants, cooperative agreement, and other non-procurement awards available from federal sources; contains no information on actual spending or R&D activity	No
Federal Assistance Awards Data System (FAADS) (Government-Wide Data System)	Contains basic tracking and spending information on all grants, cooperative agreements, and other non-procurement awards (both R&D and non-R&D) made by every federal agency.	No
Federal Procurement Data System (FPDS) (Government-Wide Data System)	Contains basic tracking and spending information on all contracts (both R&D and non-R&D) awarded by every federal agency with a value of over \$25k.	No
Federal Research in Progress (FEDRIP)	Contains detailed information on approximately 25 percent of federal R&D activities (HHS, USDA, NSF, and DVA).	Some coordination
Research and Development in United States (RaDiUS)	Comprehensive data system built with existing information that captures 80-90% of federal R&D activities, linking high-level budget information to task/award-specific spending and activity	Coordination

Table SS1.5
Data Sources on Federal Science Activity

Agency-Specific Data Sources (databases)	Description	Useful for Priority- Setting, Coordination, or Budget Allocation?
Current Research Information System (CRIS)	A database that contains information on ongoing agricultural, food and nutrition, and forestry research supported by USDA agencies	Coordination
Science and Technology Information System (STIS -NSF)	An electronic dissemination system that provides access to NSF publications	Coordination
Computer Retrieval of Information on Scientific Projects (CRISP)	Contains project abstracts for the IMPAC data	Coordination
507 System (NASA)	Database tracking basic information on contract- based award and task activities	No
Procurement and Assistance Data System (PADS)	Tracks all unclassified procurements and financial assistance made directly by DOE (does not detail activities of National Labs)	No
DOE R&D Tracking System	Contain award/task information on activities of all National laboratories and comparable R&D facilities within DOE's purview	Coordination
NIST/OD	Specially prepared detail on R&D activities accessible via RaDiUS only	No
DVA RDCC	Contains basic information on R&D task on- going within VA Medical Centers	No

Table SS1.6
Data Sources on Federal Science Activity

Agency-Specific Data Sources (budget justification)	Description	Useful for Priority- Setting, Coordination, or Budget Allocation?
ACF CFO	Budget information	Budget Allocation
AHCPR CFO	Budget information	Budget Allocation
AID CFO	Budget information	Budget Allocation
CDC CFO	Budget information	Budget Allocation
DED CFO	Budget information	Budget Allocation
DOD CFO	Budget information	Budget Allocation
DOE CFO	Budget information	Budget Allocation
DOI CFO	Budget information	Budget Allocation
DOJ CFO	Budget information	Budget Allocation
DOT CFO	Budget information	Budget Allocation
DVA CFO	Budget information	Budget Allocation
EPA CFO	Budget information	Budget Allocation
FDA CFO	Budget information	Budget Allocation
HCFA CFO	Budget information	Budget Allocation
HRSA CFO	Budget information	Budget Allocation
MMC CFO	Budget information	Budget Allocation
NASA CFO	Budget information	Budget Allocation
NIH CFO	Budget information	Budget Allocation
NIST/OD	Budget information	Budget Allocation
NOAA CFO	Budget information	Budget Allocation
NRC CFO	Budget information	Budget Allocation
NSF CFO	Budget information	Budget Allocation
Smithsonian CFO	Budget information	Budget Allocation
USDA CFO	Budget information	Budget Allocation
USGS CFO	Budget information	Budget Allocation

SPECIAL ISSUES SECTION 2. BENEFITS ASSESSMENT IN THEORY AND PRACTICE

The contribution to society from investment in fundamental science has generally been assumed to be sizeable. Finding its most significant formal policy statement in the Bush report (Bush, 1945,) it had been an operative principal for federal funding of R&D for many years. For the purposes of resource allocation, however, a better understanding of the returns to that investment and the nature of the relationship between inputs, outcomes, and social benefits would be highly desirable. The present discussion will briefly survey means for assessing benefit, the uses to which such methods are put in practice for the purpose of priority setting, and a discussion of data sources on federal R&D potentially available for budget coordination and priority setting purposes.

HOW BENEFITS TO SOCIETY ARE DETERMINED

Methods to measure the performance and quantify the benefits ensuing from fundamental science, when considered from the standpoint of their objects of study, generally fall into three classes.⁷ The first is to take an asset-oriented approach that is only a bit more illuminating than to make general assertions of the value of scientific research. While not making any strong statements on actual causal processes, the implicit argument is that one may compare R&D efforts by assessing the value of the research assets they generate: size and nature of research facilities, state and vintage of available equipment, numbers of graduates by field and specialty, etc. This asset-oriented measure is largely focused on measuring system intermediates: what tools are put in place as the result of expenditures under the federal research portfolio? The implicit proposition is that the more such assets are available, the more research may be supported which, in turn, suggests a greater likelihood of providing a positive effect on the pursuit of societal goals.

There are two additional approaches that measure results more directly in an attempt to speak to the question of ultimate value of the conducted research. The first focuses on the formal documented output of the research process, principally scientific papers, in bibliometric analyses. These methods include publication counts, citation analysis, and patent analysis.⁸ At its best, bibliometrics attempts to measure the linkages from one article to

⁷ There is a large academic literature on the theory and practice of this form of measurement. A more general bibliography and analysis may be found in (Popper, 1999.) Kostoff (1997) provides an exhaustive survey and classifies methodologies less by their objectives than by technique employed: retrospective methods (e.g. case studies,) qualitative methods (e.g. peer review,) and quantitative methods (e.g. bibliometrics; economic analyses.)

⁸ For detailed explanations of bibliometrics, see: van Raan, A. F. J., 1993. "Advanced Bibliometric Methods to Assess Research Performance and Scientific Development: Basic Principles and Recent Practical Applications," review report based on invited paper, University of Leiden Report CWTS-93-05, August; Cozzens, Susan E., 1989. "Literature-Based Data in Research Evaluation: A Manager's Guide to Bibliometrics," report to the National Science Foundation; Narin, Francis, Dominic Olivastro, and Kimberly Stevens, 1994. "Bibliometrics/Theory, Practice and Problems." *Evaluation Review*, Vol. 18, No. 1, February, pp.

another to measure the intellectual connections between organizations and the linkages between subject areas. Citation analysis can identify a group of articles that are cited together. These data can help construct a "cognitive map" of scientific research activities, identifying where science is adding value to society. These methods have individual benefits and drawbacks, but as an approach for measurement they are hard-pressed by themselves to make the connection between the outputs they measure and the influence of these outputs on the creation of social goods except in the broadest possible sense. They are, however, an important key to achieving better understanding of the process that yields scientific outcomes and ultimate social benefit.

Yet a third class seeks to measure outcomes or results effected through and by the results of scientific research. Two fundamental approaches are used. The crafting of case studies and retrospective analyses is largely a narrative method and by definition narrowly focused on following specific threads of benefit. This approach was used in the Air Force "Hindsight" study and the NSF's TRACES project and its follow-on as well as the more recent effort by NSF's Directorate of Engineering.⁹ Again, by definition, this methodology is very useful in improving our understanding of the process of discovery and innovation and in illuminating lessons for priority setting, but it is also resource intensive and necessarily takes place long after particular decisions on allocation have been made.

The application of economic techniques and concepts to results-oriented assessment yields methodologies that have been used to search for quantifiable effects ensuing from scientific research. Yet, most such approaches were developed to answer specific questions. Often in their specification they cannot capture fully the intricacies involved in the conduct of science nor the nature of scientific research as an industrial input. Such studies almost always use one of the following as the metric of performance: productivity growth, increase in national income, or cost versus benefit—particularly improvement in social welfare as measured by changes in consumer and producer surpluses. Even so, despite their limitations, economic measures are used to describe the contributions of fundamental science. The methodologies most often employed include production function analysis and social rates of return analysis.¹⁰

Production function analysis is a mathematical mapping of the inputs of a production process to its outputs. A general finding from such studies is that returns to R&D in general are high, but the returns to federal

65-76; van Raan, A. F. J., 1993. "Advanced Bibliometric Methods to Assess Research Performance and Scientific Development: Basic Principles and Recent Practical Applications," review report based on invited paper, University of Leiden Report CWTS-93-05, August.

⁹ Illinois Institute of Technology Research, "Technology in Retrospect and Critical Events in Science", 1968; Director DDR&E, "Project Hindsight", DTIC No. AD495905, 1969; Battelle Columbus Laboratories, "Interactions of Science and Technology in the Innovative Process: Some Case Studies", 1973.

¹⁰ There are, of course, alternative ways to categorize studies in the aggregate assessment literature. Hertzfeld (1990) offers a useful classification scheme for studies on the contributions made by fundamental research. Rather than utilize methodology as an organizing principle, he establishes five categories to group studies by issue: (1) research output at the sectoral level, (2) measurement of social welfare, (3) evaluation of emerging technologies, (4) research infrastructure development, and (5) research structure efficiency.

expenditures on R&D are low.¹¹ Yet, in many ways federal research presents greater problems for measurement and benchmarking than does private R&D. Much federally funded research is directed to areas where there is only a limited market at best. Further, given the types of data available, the returns that result from most calculations must be interpreted as average rather than marginal rates. From the policy perspective, this means we cannot be certain of the implications to draw from this aggregate analysis for what the effect of an additional dollar of expenditure on research might be. The cost/benefit framework itself may itself be too restrictive, failing to capture the many types of benefit, which may be derived from publicly-funded basic research. The true effect of such outlays may well be indirect, affecting productivity through changing the returns to private research and development rather than directly as a result of the specific research project.

Social rates of return analysis departs from the narrow specifications of a production function and seeks to determine the sum of benefits accrued from changes in the knowledge base and compares these benefits to the cost of investment. These benefits are most often measured as changes in consumer and producer surplus. This social benefit may be considerably greater than the private benefit taken in the form of profit. As a practical matter, such studies involve selecting a sample of specific innovations upon which to perform these calculations. This is both expensive and subject to unintentional or unavoidable bias of one sort or another in the selection process. Further, the social rate of return calculated by such means is not directly comparable to the internal rates of return calculated for private investment projects. Nevertheless, studies in this area have found a very high return to investment in basic research. In a much publicized result, one paper found a 28 percent return to investment in academic research.¹² Yet, here again, the principal outcome from such studies is to suggest the need for other analyses to address specific aspects of concern.

UTILIZATION OF BENEFITS MEASURES IN PRIORITY SETTING AND BUDGET COORDINATION

Who are the customers of such methods for calculating benefits from scientific research? Within the government it is perhaps not surprising that the National Science Foundation was an early and major funder of such work. However, it is only recently that that agency and others have begun to consider how the methods and findings

¹¹ Some summaries of the studies which support these stylized facts are Zvi Griliches, 1973. "Research Expenditures and Growth Accounting," in *Science and Technology in Economic Growth*, B. R. Williams, ed. (New York: Wiley) pp. 59-83; Zvi Griliches, 1980. "Returns to Research and Development Expenditures in the Private Sector," in *New Developments in Productivity Measurement and Analysis*, J. W. Kendrick and B. N. Vaccara (eds.) (Chicago: University of Chicago Press) pp. 419-454; Albert N. Link, 1981. "Basic Research and Productivity Increase in Manufacturing: Additional Evidence", *American Economic Review*, vol. 71, pp. 1111-1112, December; Terleckyj, E. Nestor, 1974. *Effect of R&D on the Productivity Growth of Industries: An Exploratory Study*. (Washington: National Planning Office; and Terleckyj, E. Nestor, 1980. "Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries," in Kendrick and Vaccara, op. cit., pp. 359-377. Of particular interest for the purpose of this literature review is P. S. Kochanowski and Henry R. Hertzfeld, 1981. "Often Overlooked Factors and Measuring the Rate of Return to Government R&D Expenditures", *Policy Analysis*, vol. 7, pp. 153-167.

¹² Mansfield, Edwin, "Academic research and industrial innovation," *Research Policy*, Vol. 20, 1991, pp. 1-12.

produced by such efforts may be used operationally to assess performance and inform decisions over priority in funding.

One principal potential customer of such information is Congress. Whether it acts as the originator of information requests for the purposes of furthering its own process, or is targeted as the ultimate audience for assessments produced for its benefit by the agencies coming before its committees for funding, Congress would like to have better means for determining the results ensuing from federal funding of R&D. The most recent reiteration of this desire from the Congressional standpoint is found in the recent report of the House Science Committee (U.S. Congress, 1998). However, this document reinforces that there is still a lack of any well-documented connection between ultimate results and ex ante calculations of benefit. This provides in large part the motivation for continued support to curiosity-driven research (p. 13). To the extent Congress should seek to measure success in this areas it should be done on an aggregate portfolio and not on individual research project basis (p 22.)

Another body which has considered broad application of performance-based measures throughout the federal government is the NSTC. That body has issued a list of performance measures for function 250 (R&D) activities:

- the federally funded research is to be of "high quality"
- encourage setting aside 80 percent or more for peer-reviewed competition
- encourage assessment of programs by external bodies
- build and operate major scientific facilities efficiently
- and meet federal time and cost guidelines for facility upgrades and minimal down time (NSTC, 1998; p. 30).

As may be quickly seen, these are in reality guidelines for conduct and measures attuned to the first category found in the literature: asset-based measures. There is no discussion of applying measures in terms of either direct outputs or indirect outcomes.

The work of the National Academy of Sciences provides a further example of this approach. This body, and in particular its Committee on Science Engineering and Public Policy (COSEPUP,) has suggested assigning priority to areas of science in such a way that the U.S. is positioned among the leaders in all fields. Hence, there is a natural gravitation toward enabling more effective international benchmarking as a purpose for assessing benefits. The general guidelines suggested by COSEPUP are: 1) What is the U.S. position in a field? 2) What key factors determine relative position? and 3) What is the trend for relative position in the near and long term? (NAS 1998, p. 15) Due to their aggregate nature, these yardsticks do not necessarily track well with those of potential use to mission agencies. Further, in application, most actual measures employed again appear to be of the asset-accounting type. In a pilot study of materials science intended to implement this type of assessment, COSEPUP utilized the following measures:

- National imperatives as an influence on S&T
- Innovation
- Major facilities

- Centers
- Human resources
- Funding (NAS 1998, p.27.)

Most of these are a matter of weighing of assets. The first and especially the second are more matters of interpretation. Only the latter can truly be considered to be a measure of either direct outcome or indirect results.

At the agency level, the DOE Office of Science Strategic Plan lists a series of success indicators for each of its five main goal areas (e.g.: "photochemical systems that hold promise for economical, highly efficient solar cells.") The indicators are outcome-oriented but seem to be of a checklist-type, attuned to achieving particular milestones and not quantitative in nature. They do not seek to track direct benefit back to specific R&D project outcomes (DOE, 1999.)

Documents on the performance assessment process in use by NSF point to heavy reliance on external assessment. Attempts are being made to shift from a somewhat ad hoc basis to a more formal procedure that will provide a common format to the review process that extends across NSF. In addition, beginning in 1998, annual reports to the Director have been required from NSF units using a variety of indicators and data series to demonstrate effect (NSF, September 1997.)

Results from NSF awards appear over time. Thus, in assessing performance toward the outcome goals during a given year, NSF must look carefully at (1) noteworthy achievements of the year based on NSF awards, (2) the ways in which projects collectively affect progress, and (3) expectations for future performance based on the current set of awards. (NSF, Jan. 99, p. 15)

This states the first of the two main problems in assessing benefits and using the results in priority planning at a program, directorate, or even agency level: it is difficult to establish causal linkages between research and outcomes over time. However, in this regard NSF has explicitly addressed the other problem that usually bedevils the practical use of this type of assessment. It has attempted to spell out the goals it seeks to achieve from its endeavors. The NSF GPRA performance plan, as amended, contains a series of goals and levels of performance. For the more difficult, outcome-oriented of the goals (e.g., "Outcome Goal 2: Connections between discoveries and their use in service to society"), the principal means of assessment appears to be reliance on expert judgement and external directorate advisory panels. As such, the assessment is principally qualitative. Those goals that are more management or facilities oriented naturally find an easier time in stating quantitative measures of output.

The academic literature continues to suggest new means for assessing benefit and applying to considerations of priority. As an example, an options approach has begun to receive some attention (Vonortas, 1999.) The intention is to formally reduce uncertainty through a phased decision process that might also more easily support handing off of funding responsibilities from the public to the private sector as technology opportunities become more apparent. Yet, an examination of the agency-generated literature seems to bear out the conclusions arrived at by Kostoff (1997) in his exhaustive *Handbook of Research Impact Assessment*:

While the methods used in the performance of research continually advance the state-of-the-art, the methods used for its identification and selection have changed little in decades. In evaluation and assessment of existing and completed research, not only have the methods in practice changed little with time, but the numbers of organizations which use any but the most rudimentary methods also remain a handful. While the scientific and social science literatures abound with advanced methodologies for identifying and selecting new research, managing existing research, and evaluating and assessing research retrospectively, the implementation of these methods by the research sponsoring community remains minimal (p.4.)

Yet, the difficulties in applying the measurement means developed by academics should not be underestimated. Questions of measurement revolve around certain conceptual issues of model specification, data, and policy. All approaches to measurement utilize models which are at best approximations of a technical relationship. In the context of these models, several general issues recur irrespective of method: (Popper, 1999)

- Basic research is conducted in a wide range of fields. The mechanisms for integrating research findings with practical development work may differ considerably from field to field.
- All the surveyed approaches carry an implicit assumption of linearity. Yet, it is precisely the non-linearities and interdependencies which are the hallmark of the innovative system and make the attribution of causality so difficult.
 - There are qualitative differences between knowledge as an input and the more traditional inputs of capital and labor. The proxies we use for the former are less satisfactory measures of value than those used to measure the latter two.
 - Concrete and formalized research findings are the most obvious product of basic research. There are other less formal outputs that may have as great an effect on economic and social goals. These include:
 - Training in scientific fundamentals.
 - Expertise and experience.
 - Network formation.
 - Experimental design and protocols.
 - Increased number of guesses about nature and greater chance for serendipity.
 - An option for future action.
 - Negative results.
 - Intangible benefits.

This underscores a need to examine the assumptions underlying any particular method for measuring performance. It also raises issues of data if benefits assessment is to be seriously attempted.

APPENDIX A. FULL TEXT DESCRIPTIONS OF AGENCY PRIORITY SETTING ACTIVITIES DESCRIBED IN THE LITERATURE

Department of Defense

Literature on priority setting in the Department of Defense (DoD) is scarce. Nonetheless, in addition to the 1991 OTA report, a few documents were found regarding priority setting; these included several DoD annual reports and an S&T strategic plan as well as a RAND study on "Priority Setting and Strategic Sourcing in the Naval Research, Development and Technology Infrastructure," (Saunders, 1995).

According to Chapter 16 of DOD's 1997 Annual Report, planning for Science and Technology occurs in the office of the Director of Defense Research and Engineering (DDR&E). DDR&E looks to the NSTC and the Joint Chiefs of Staff's Joint Vision 2010 for guidance. The S&T plans are created in two ways. First, overall future needs are set by program planners; then, planners try to match technology with program goals. If current technology cannot meet future goals, strategies are created to develop new technologies. Second, planners may also start from a possible scientific opportunity and tailor programs to explore that opportunity. In addition to these guiding principles, the DoD S&T program sets forth plans for the Joint Warfighting S&T Plan (JWSTP), Defense Technology Area Plan (DTAP), DoD Basic Research Plan, and various plans of the Military Departments and Defense Agencies.

In its Basic Research Plan, DoD uses peer review and competition to achieve its objectives. In soliciting new ideas, DoD uses the broad agency announcement process, electronic media, and other mechanisms to reach the scientific community. Also, the Deputy Under Secretary of Defense for Science and Technology establishes Technology Area Reviews and Assessments (TARA) as an oversight function to assess the quality of the research programs. The TARA review teams consist of technical experts from academia, industry, and not-for-profit research organizations. These teams evaluate the programs for quality, for advances in leading the state-of-the-art in research areas, and for their scientific vision.

Within the DDR&E operates the Defense Advanced Research Projects Agency, DARPA. Created in 1958, DARPA's mission is to "...develop 'revolutionary' technologies that can make a significant impact on the future of the United States' defense posture, and to ensure that those technologies effectively enter the appropriate forces and supporting industry base." As OTA notes, priority setting within DARPA is very different from that at other DOD research agencies. Project managers "are not attempting to maintain strength across a field, rather they are funding good *ideas* that are on the forefront of technology development to meet desired objectives." (p. 105) DARPA program managers are guided in decision making by recommendations established in the JWSTP and the more detailed DTAP. The JWSTP and DTAP are drafted as a result of direct interaction in a series of meetings between technical area experts, scientists, the portfolio manager (DARPA) and the intended consumer -- the military services. These meetings, in turn, are informed by a set of Joint Warfighting Capability Objectives (JWCOs) issued

by the Joint Chiefs in concert with OSD and service science and technology planners and decision makers. Individual JWCOs are then assessed by teams assigned to each during the TARA process. The practice ensures that at least two-thirds of the TARA membership comes from *outside* DOD.¹³ The process results in the drafting of the JWSTP and DTAP documents.

As for other DOD services, OTA notes that "compared with basic research funding for other research agencies, the services show remarkably little fluctuation in allocated finds, adjusted for inflation." (p. 111) Reports on other services' priority setting activities are limited.

In 1995, the Department of the Navy (DON) contracted RAND to conduct a study on priority setting in research and development in the Navy. The RAND study presented a framework intended to aid the DON in setting funding (or support) priorities for various lines of RD&T. The RAND framework was comprised of "four coupled (interdependent) steps: assembling a list of RD&T capabilities, defining criteria or dimensions along which the capabilities can be evaluated, ranking the capabilities according to criteria, and translating the criteria rankings into support priorities." (Saunders, 1995) The framework, rather than the application of it, was regarded as the primary output of this project. To arrive at final sets of RD&T funding priorities, DON itself applies the framework to its process.

According to OTA, much of Army research is closely linked to priority setting for all of the R&D funds in the Army's laboratories and institutes. "Laboratories in the Army act independently, although they determine priorities in relation to overall directives from Laboratory Command." Most are "industrially funded" competing for funds from sources within and without the Army. (p. 105)

Department of Energy

According to the OTA study, the Secretary of Energy instituted a strategic planning process within DOE in the late 1980s. A National Energy Strategy (NES) was designed to solicit input from the offices within DOE and from external advisors:

In the Office of Energy Research, programs such as Basic Energy Sciences and High Energy and Nuclear Physics use an "iterative" process of priority setting-where ideas are proposed (with origins both within and without DOE), feedback from the scientific community and other parts of government are received, and the proposal is revised...to determine goals. In particular, as national goals are defined and new ideas arise from either within DOE or without, the program will first consider them internally. If the new initiative would fit into the existing program or complement it, then the idea will be fielded to a wider audience. Sometimes this audience includes only other parts of the agency. DOE may, however, hold public workshops and/or panel meetings to devise a plan of action. (OTA, 1991; p 110)

¹³ This process is exceedingly labor intensive. One study seeking to explore new technical means to make more practicable the types of interactions required for the full operation of this model may be found in Lempert (1998.)

In addition, each program has an advisory panel, such as the High Energy Physics Advisory Panel, an external board of scientists. This group and others like it present to DOE programs a set of priority research areas that deserve the agency's special attention.

According to publications from the Department of Energy's Office of Science, the office's stated goal is to pursue scientific excellence in energy research (DOE, 1999). In selecting areas of research, the Office of Science emphasized the use of peer review to evaluate all programs. It also stated that advisory boards play a significant part in its priority setting processes. As input to the Office of Science 1999 Strategic Plan, two workshops were held. In the first workshop, the participants—a group of scientists, technologists, high tech managers and science communications people from across all areas of government, industry and academia—established overarching themes in the energy sciences. These themes included: improving fuels and power for an energy-efficient future; cleaning up the environment; preventing waste and pollution, protecting human health; discovering the answers to the basic secrets of the universe; and providing the tools to enable cutting-edge research. In the second workshop, after several debates and discussions, these themes were broken down into five specific goals: establishing clean and affordable energy; protecting the planet by studying how energy impacts people and the biosphere, exploring matter and energy, providing cutting-edge tools for science; and pursuing scientific excellence. Under each of these goals, three objectives were created; and under each objective, strategies were set to attain the goals. For example, an objective of the Fuel for the Future program is to "advance the science for the development of new and improved sources of domestic fuels." The strategies listed under this objective show that the Office of Science will invest in chemistry and material science for energy conversion, and will conduct research in plant, microbial and solar conversion, and continue research in the geosciences.

The DOE R&D and Technology Roadmapping Framework in its strategic plan states that "Each planning team shall ensure that the R&D technology roadmaps development under the direction of the Under Secretary are fully integrated into the goals, objectives, performance goals, and strategies of the strategic plan. Laboratory input will be necessary to accomplish this. However, this does not mean that each team needs to develop an objective for R&D or technology. Other than the Science mission area, R&D and Technology Roadmapping will likely be a cross-cut topic and not meet the budgetary criteria for its own objective.

National Aeronautics and Space Administration (NASA)

NASA R&D priorities are influenced more heavily by Congressional mandate than those of other agencies, particularly with regard to large scale efforts. According to OTA, the Office of Space Science (OSS) "sets priorities in conjunction with the budget process and by selecting specific projects. The process is essentially bottom up with project managers proposing new initiatives. However, when large missions are proposed, such as Space Station Freedom, top-down direction will determine the parameters of the effort." (OTA, 1991; p. 107)

Priority setting in NASA's Office of Space Science (OSS) is a combination of input from its own internal managers, staff and directors, and external actors like the National Research Council (NRC) and the space science community. In December 1995, the OSS asked the NRC's Space Studies Board to update the 1991 Bahcall report

on scientific priorities for space astronomy and astrophysics. In its goal to pursue scientific excellence, the Office of Science emphasized the use of peer review to evaluate all programs. It also stated that the advisory boards will also play a significant part in its priority setting processes. According to OTA:

The National Research Council (NRC) plays a particularly strong advisory role for OSSA, and the Space Studies Board provides input for most NASA basic research programs. The board is unique at NRC because it has an *institutional* relationship with NASA, i.e., NASA funds the board and requests many studies, but the board can use these resources to initiate studies independently. In fact, the board has been able to preserve its credibility because it has not always agreed with NASA, and has openly disputed it on some occasions. Roughly every 10 years, if events do not call for an earlier revision, the board writes a strategic plan for every discipline in OSSA. The Space Studies Board also conducts periodic reviews of the programs and every new mission, and other larger topics such as "manned" vs. "unmanned" flight are routinely studied. In addition, OSSA has an internal structure of advisory panels. The panels are usually made up of representatives from academia, industry, Federal laboratories, and other interested groups such as program managers from other agencies. They are consulted at least once or twice each year (sometime quarterly) about future directions for research programs. However, as with NRC, their findings are never binding. (OTA, 1991; p 113)

In response to NASA's 1995 request, the NRC established a Task Group on Space Astronomy and Astrophysics (TGSAA). TGSAA split itself into four panels: Planets, Star Formation, and the Interstellar Medium; Stars and Stellar Evolution; Galaxies and Stellar Systems; and Cosmology and Fundamental Physics. Forty-six experts were selected to serve on these panels. The panels engaged in debate, discussion, and a series of ballots to draft a series of final priorities. The committee used several approaches in establishing the draft priorities. It tried to "concentrate on scientific objectives rather than the methods by which the objectives are implemented, it prioritized scientific questions of significance, committee members were realistic to cost and technical feasibility". The process resulted in a report entitled *A New Science Strategy for Space Astronomy and Astrophysics*. The OSS then used this report as input into its 1997 strategic plan.

In the 1997 Strategic Plan, the OSS proposed near-term (2000-2004) and long-term (2005-2020) priorities. The plan established seven fundamental questions that form the foundation for the office's scientific program. It then incorporated the advice of the NRC as well as others in the space science community in establishing "Enterprise Goals" *, "Science Goals", and more specifically, "Science Objectives". For example, under the category of Fundamental Questions, OSS asked, "how did the Universe begin and what is its ultimate fate?" Under the category of Enterprise Goals, OSS stated that it wanted to "establish a virtual presence throughout the solar system, and probe deeper into the mysteries of the Universe and life on Earth and beyond." Under Science Goals,

OSS stated that it needs to "understand how structure in our Universe (e.g., clusters of galaxies) emerged from the Big Bang. And, under Science Objectives, we need to "observe the earliest structure in the Universe."

Department of Health and Human Services, National Institutes of Health

NIH is the largest player in the Federal Government in terms of dollars awarded to basic and applied research. It is the principal biomedical research arm of the U.S. Department of Health and Human Services (HHS), funding biomedical and basic research related to a broad spectrum of diseases and health problems both in its own research facilities (the NIH laboratories) and in external organizations. In terms of goal setting at the agency, "since the 1960s, the goals and justifications for health research have been fairly constant-improving the health of the American people, curing particular chronic diseases, and contributing to the economic well-being of the Nation by producing a healthier work force. However, particular emphases have shifted." (OTA, 1991; p. 99) Generally, these shifts have occurred as new scientific developments have changed the landscape for medicine.

The priority setting process in the twenty-one National Institutes of Health consists of input from Congress and the science community as well as from NIH directors and staff:

Each institute has an advisory council, which is appointed through HHS and is made up of scientists and lay people. Program officers must go before the council to present ideas for new programs, and councils review program balance. Each institute may also form advisory committees with programmatic foci; for example, NHBLI has six committees to assist in specific fields. Committees help develop new initiatives. It should be noted, however, that the council is only advisory, except for its ability to approve or disapprove grant applications. (OTA, 1991; p. 100)

According to NIH documents, the director of each Institute, with the help of NIH's national advisory council, decides funding for grants and programs. The council is mandated by Congress and is composed of people from both the scientific community and the public. It meets three or four times a year to review grant applications and to make recommendations on matters of policy and research emphasis. In addition to the council, the director also consults with intramural investigators, scientists in the extramural program, with groups of patients and their families interested in research on particular diseases, with professional and scientific groups, with representatives of the Administration and members of Congress, and with the public.

In 1997, the NIH published "Setting Research Priorities at the National Institutes of Health". In this booklet, the NIH lists five criteria on which the Institutes base their allocation of resources. These criteria include the health needs of the public, the scientific quality of the research, the potential for scientific progress, adequate support of infrastructure (human capital, equipment and instrumentation, and facilities) and a need to diversify the

* The OSS intends to accomplish the scientific investigations related to Enterprise and Science goals within a five to six

research portfolio along the broad and expanding frontiers of research. Within each category listed above there are criteria that help each manager decide on the best course for funding. For example, when setting criteria for the health needs of the public, the NIH looks at a combination of factors, such as the number of people who have a particular disease, the number of deaths caused by a disease, the degree of disability produced by a disease, the degree to which a disease cuts short a normal, productive, comfortable lifetime, the economic and social costs of a disease, and the need to act rapidly to control the spread of a disease.

When institute staff notice evidence of an emerging area of research, "they assess the importance of the new field and gauge interest and capabilities. They can then convene a meeting or workshop, write up a proposal for a new program, and go to their council for approval. If the program does not have a known constituency, an institute will often issue a request for applications." (OTA, 191; p. 100)

Despite the existence of these internal mechanisms for its priority setting process, NIH has shown concern over methodology and an interest in receiving external validation of its process. NIH contracted the National Research Council to look into four issues related to setting priorities: allocation criteria, the decision-making process, mechanisms for public input, and the impact of congressional directives. The resulting report, *Scientific Opportunities and Public Needs* (NAS, 1998,) recommended that in setting priorities the NIH should continue to use its current criteria. Nevertheless, it should also try to create a better public understanding of its priority process and the NIH should be more systematic and use more formal mechanisms to obtain and analyze the data used in priority setting. In regards to the actual priority setting process, the committee recommended allocating greater power to both the NIH director and his advisory committee. The NRC stated that directors of all of the institutes and centers supply multiyear strategic plans, including budget scenarios, to the NIH director; and that there should be a greater involvement of the Advisory Committee in the priority-setting process.

The National Science Foundation

The primary role of NSF is to support basic research and science education across broad categories of science and engineering. This is done primarily through support for university-based individual investigators. The NSF long range planning cycle is part of and preparatory to preparing the budget in each year. "Divisions and Directorates consider scientific opportunities, issues and constraints confronting them as well as national needs and trends with the object of articulating priorities and formulating new initiatives" (NSTC, 1998). The efforts are intended to track into four core strategies for achieving broad agency mission goals:

- develop intellectual capital
- strengthen the physical infrastructure
- integrate research and education
- promote partnerships.

The NSF process for strategic planning involves calling in NSF advisory committees of visitors, regular reviews of programs and input from the National Science Board, and at the Directorate level reports from external groups on program issues (NSF, 1997). (NSF, perhaps owing to the specialized nature of its mission, is the only mission agency whose plans explicitly consider integration with those of others. This is principally done through personal interaction at the program level between NSF portfolio managers and their opposite numbers.)

Further, OTA describes the process within NSF as "very much a bottom-up process. Goals are set by scientific opportunity and the proposal process, as well as in special initiatives from advisory panels." OTA provides further illustration:

The agency primarily sets priorities and plans through a process described by many as "...continuous, open, and decentralized." The decision cycle is keyed to the annual Federal budget and annual appropriation cycles. Eight populations provide formal and informal input into the planning process. They are: 1) the National Science Board; 2) advisory committees; 3) professional societies; 4) NRC; 5) Visiting Scientists, Engineers, and Educators (also known as "rotators" '); 6) NSF staff; 7) the Inter-Directorate Task Force; and 8) Congress. (OTA, 1991; p. 114)

Setting NSF apart from other agencies is the role of the National Science Board (NSB) in priority setting. According to OTA, decisions made within the agency are forwarded to the NSB for consideration in the strategic plan.

A strategic plan is developed that must be set against the general recommendations of NSB. For example, in 1989, NSB decided on four general priorities for NSF to pursue: international cooperation in research, education, economic competitiveness, and better methods for leveraging Federal dollars (i.e., to share funding with other-typically State or private-sources). (OTA, 1991; p. 115)

"The National Science Board (NSB) is specifically charged with assessing the health of science in the Nation and with advising the President and Congress on matters of national science policy." A particular responsibility of the Board in implementing this mandate is the biennial publication of Science and Engineering Indicators. [cited in the National Science Foundation Act of 1950, as amended, 42 U.S.C. Sec. 1861.et. seq] (NSB, 1997)

The NSB recommended that the following two criteria be adopted in place of the four criteria that had been used in the past to determine research priorities: What is the intellectual merit of the proposed activity? E.g., does it advance knowledge and understanding in its own field and across fields? Is it creative and original? What are the broader impacts of the proposed activity? E.g., advance discovery and promote teaching? Enhancing partnerships? This criterion relates to the potential of the proposed research to contribute to better understanding or improvement of the quality, distribution, or effectiveness of the Nation's scientific and engineering research, education, and manpower base." NSF has also cited the following criterion:

...questions relating to scientific, engineering, and education personnel, including participation of women, minorities, and disabled individuals; the distribution of resources with respect to institutions and geographical area; stimulation of high quality activities in important but underdeveloped fields; support of research initiation for investigators without previous Federal research support as a Principal Investigator or Co-Principal Investigator and interdisciplinary approaches to research or education in appropriate areas. (OTA)

United States Environmental Protection Agency (EPA)

The U.S. EPA's mission is to protect human health and to safeguard the natural environment—air, water, and land—upon which life depends. Within the Agency, EPA's Office of Research and Development (ORD) has the principal responsibility for research and development. According to the National Academy of Public Administration (NAPA) report, "Setting Priorities, Getting Results: A New Direction for EPA," ORD's 1995 Strategic Plan relied heavily on EPA's Science Advisory Board (an independent group of engineering and science advisors to EPA) and expert panels convened by NAPA and the National Academy of Sciences (NAPA ;NAS, 1995). In late 1995, ORD distributed a review draft of the strategic plan to solicit comments from external partners and stakeholders. Based on peer reviewer comments, ORD refined and expanded the strategic plan to produce the final version, *ORD's Strategic Plan* (EPA, May 1996).

The most important of EPA's strategic principles is the explicit use of the risk paradigm to shape and focus EPA's organizational structure and research agenda. Risk assessment is the process that scientists use to understand and evaluate the magnitude and probability of risk posed to human health and ecosystems by environmental stressors, such as pollution or habitat loss or change¹⁴. The risk assessment process consists of four steps: hazard identification, dose response assessment, exposure assessment, and risk characterization. Risk management options may include both regulatory programs and voluntary activities (e.g., recycling) to reduce or eliminate production of the stressor. The risk assessment paradigm has been defined many times over the years, most notably by the NAS, which consolidated and gave context to terms that had been defined in different ways up to that point (NAS, 1983; NRC, 1994; NRC, 1996). The general principles set forth in the NAS paradigm are still useful as an organizing focus for ORD's strategic thinking. ORD's commitment to develop a risk-based research agenda has required a risk-based process for selecting and ranking those research areas of primary importance to EPA. ORD provides suggestions for improving science at the EPA in order to institute a more effective, risk-based research program. For example, ORD reorganized their nationwide system of laboratories to conform to the fundamental components of the widely used risk assessment and risk management processes. With its Strategic Plan, ORD instituted a new system for determining research priorities based on risk assessment and risk management principles.

¹⁴ Davies was at the forefront of the use and potential use of comparative risk for priority setting. Davies noted that while there is a need for priority setting using risk comparisons, the limitations of the tool must also be considered (Davies, 1996)

EPA's strategic plan promotes greater partnership between ORD and its primary clients—EPA's Program and Regional Offices and the external scientific community— by providing clear mechanisms and opportunities for stakeholder involvement. EPA's strategic plan includes a detailed description of how ORD translates its research priorities into a research program, as well as a discussion of EPA's commitment to providing the infrastructure needed to conduct high quality research.

Department of Commerce – National Institute for Standards and Technology

According to agency documents and Congressional testimony, the National Institute of Standards and Technology (NIST) sets priorities in specific measurement areas based on the advice of councils created by NIST itself but which are established as independent nonprofit organizations. For example, NIST sets priorities in optical radiation and ionizing radiation measurement based on the advice of two councils created by NIST and established as nonprofit organizations. The Council for Optical Radiation Measurements (CORM) was established in 1972 to determine "Pressing Problems and Projected National Needs in Optical Radiation Measurement". CORM is composed of members from government, industry and academia. The Council strives to provide a consensus on industrial and academic requirements for standards and programs, including setting priorities. CORM was so successful in setting priorities that NIST established a Council for Ionizing Radiation Measurements and Standards (CIRMS). However, NIST also uses a very different approach to priority setting for its service-oriented division, Time and Frequency. This division maintains direct contact with customers and manufacturers. This one-on-one contact in addition to periodic customer surveys has allowed NIST to set priorities based on customer need. By working with its customers, NIST is able to answer what it feels is its fundamental question for priority setting, "Do our research programs meet the present and future measurement needs of the United States?" (Gebbie, 1996).

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Arthur Andersen. *The Costs of Research: Examining Patterns of Expenditures Across Research Sectors*. Report for The Government-University-Industry Research Roundtable, March, 1996.

Arthur Andersen's analyses concluded that the pattern of expenditures incurred for research activities in federal laboratories, universities, and industry are strikingly similar, despite common perceptions that there are wide differences.

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This report makes five major recommendations, first among them a call for a nongovernmental national R&D forum to "identify ways in which science and technology can contribute to the definition and refinement of societal objectives and to their realization." In addition, the report recommends that Congress increase its oversight; that congressional research bodies pay more attention to linking S&T to national goals; that OSTP and OMB collaborate more closely in establishing long-term S&T goals; and that agencies pay greater attention to policy analysis and strategic planning.

— *Science, Technology, and Congress: Organizational and Procedural Reforms*. New York, NY: Carnegie Commission, February, 1994.

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In laying out the foundation for Clinton administration's support for science, this document lists important national goals to which science can contribute: health, prosperity, national security, environmental responsibility, and improved quality of life. These goals should be met by maintaining leadership across the frontiers of scientific knowledge, enhancing connections between basic research and national goals, stimulating public-private partnerships, ensuring excellence in science education, and raising scientific literacy.

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This report addresses the ways in which U.S. industry, government, and academia have been responding to the R&D environment since the end of the Cold War. The council's central finding is that R&D partnerships hold the key to America's future. The report examines the role of partnerships in R&D innovations in the aircraft, automotive, chemical, electronics, information technologies, and pharmaceuticals sectors. Finally, the report provides some policy guidelines for the nation, for industry, for government, and for academia. Specifically, the council states that the distinctions between basic and applied research need to be reevaluated to account for R&D risks in the short, medium, and long terms. It calls for government and industry to work together in choosing future R&D investments. The report also states that federal research should reflect today's missions and budget environment.

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This paper covers the history of federal R&D support and the emergence and growth of industrial R&D. The authors suggest four models of federal support for R&D. The first model proposes that federal R&D support would be for defense purposes only, eliminating federal support for all other

R&D activities. Private industry would be responsible for funding all R&D not related to defense. In the second model, federal R&D support would cover defense, environmental clean-up, space, and public health; 70 to 80 percent of funds would be for defense R&D with the remainder going toward the other areas. The third model would reduce federal R&D funding by 30 to 50 percent and would treat universities and the private sector as equal partners in R&D enterprise. In the fourth model, federal R&D support would mainly cover basic research, applied R&D would be reduced by 30 percent.

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— *Science and Technology Shaping the 21st Century*, Washington, D.C., April 1997.

This biennial report from the President to Congress on S&T addresses the administration's portfolio for S&T in security, health, environment and human resources. The report address (1) continuing American leadership in the S&T enterprise; (2) strengthening science, math, and engineering; (3) providing for a sound fiscal and regulatory environment for research; and (4) retaining a long-term commitment to research, education, and innovation.

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- President's Committee of Advisors on Science and Technology (PCAST) Executive Order and Amendments, Executive Order 12882, 23 November 1993.

Gebbie, Katherine. "Prepared Statement of Katherine Gebbie, Director, Physics Laboratory, National Institute of Standards and Technology Before the House Committee on Science Subcommittee on Technology." May 2, 1996.

In her testimony, Katherine Gebbie provides several ways in which NIST sets priorities among its R&D investments. Specifically, she provides a model in which NIST looks to two nonprofit councils, composed of government, industry and academe, to advise it on setting priorities while also discussing another model that is survey driven and involves customer feedback.

General Accounting Office. Measuring Performance: Strengths and Limitations of Research Indicators, RCED-97-91

The Research Roundtable, an HHS-led interagency group, developed guidance for R&D performance measures. The GAO described the difficulties of developing research outcomes measures.

Glauthier, T. J., "Research and Development Priorities and Reinventing Government," *AAAS Science and Technology Policy Yearbook 1995*, Washington D.C.: American Association for the Advancement of Science, 1995, pp. 57-62.

This article examines the current pressures on the federal budget and the Clinton administration's efforts toward reinventing government. Specifically, the article recommends that the science community (1) identify the implications and priorities of all programs being put together, which programs work and which do not; (2) explain these programs in laymen's terms, for congressional and public consumption; and (3) reinvent programs by including industry, universities, and government in the decisionmaking process.

Hertzfeld, Henry R. "An Assessment of Studies of the Contribution of Fundamental Research," draft submitted to the National Science Foundation, Directorate for Science, Technology, and International Affairs, Division of Policy Research and Analysis, October, 1990. [photocopy dated May 11, 1992]

Hill, Christopher T., "On the Allocation of Federal R&D Funds," working paper, Fairfax, Va.: The Institute of Public Policy, George Mason University, January 1995.

This paper covers a broad overview of present-day allocation of federal R&D funds among national purposes, performers, and federal agencies. It describes the historical processes that have helped shape R&D allocation. R&D spending responds to national crises; political and budgetary imperatives; and occasionally, to determined efforts of highly committed interests pursuing long-term visions of a different future. Rarely does the R&D portfolio reflect a carefully considered balance

among national needs, and it does not appear to take account of the overall vitality of the national R&D enterprise.

Knezo, Genevieve J., *Research and Development Funding in a Constrained Budget Environment: Alternative Support Sources and Streamlined Funding Mechanisms*, report for Congress, Washington, D.C.: Congressional Research Service, The Library of Congress, April 5, 1996.

This report summarizes cuts made in federal R&D funds, proposals to increase nonfederal sources of funding, proposals to improve R&D priority-setting, and ways to streamline and alter existing R&D award processes to make them more efficient. Specific topics include limiting federal R&D support to targeted areas; creating a Department of Science and Technology to coordinate federal R&D funding; expanding support to such alternatives as lotteries, state funding, and foundations; revising the tax code to promote R&D; modifying grant mechanisms to conserve resources; and eliminating conservation of peer-reviewed science.

— *Research and Development: Priority Setting and Consolidation in Science Budgeting*. The Committee for the National Institute for the Environment, Research and Development: Priority Setting and Consolidation in Science Budgeting II. October, 1999.

— "Defense Basic Research Priorities: Funding and Policy Issues, CRS Report for Congress, Washington, DC. Congressional Research Service, Oct. 24, 1990.

Kostoff, Ronald N. *Handbook of Research Impact Assessment*, 7th Edition, DTIC Report No. ADA296021, Summer 1997.

Lederman, Leon M., *Science: The End of the Frontier?* Washington, D.C.: American Association for the Advancement of Science, January 1991.

This is a formal survey conducted to gauge the state of academic research in U.S. universities. University faculty were asked about their experiences with research funding. Questions were asked about research funding in the scientist's own research area, the relative ease or difficulty of obtaining funding, experiences with research funding for the future, and factors influencing the ability of scientists to conduct research in their current settings. The results show that academic research is in trouble; research funding is diminishing; and morale is flagging. According to the AAAS, university funding, when corrected for inflation, was only slightly higher in 1990 than it was in 1968. The report concludes that, to balance the complexity of science, the United States should be spending twice the amount it was investing in 1968, or \$10 billion/year, and this investment should increase least 4 percent per year. The report further recommends establishing a commission to deal with this issue, consisting of representatives from the Executive and Legislative Branches of the federal government, industry, the financial community, and the academic community.

Levine, Candice S., "Reorienting for Sustainable Development: Support for a National Science and Technology Policy," *Journal of International Affairs*, Spring 1998.

This article discusses R&D funding as it pertains to the environment. In general, the article states that poor coordination among federal agencies and inconsistent support from national leaders result in a poor national science policy that will hinder sustainable development.

McLoughlin, Glenn J., *International Science and Technology: Issues For U.S. Policymakers*, Report for Congress, Washington, D.C.: Congressional Research Service, The Library of Congress, September 16, 1994.

This report presents a comparison of national R&D funding issues and options, how other nations set S&T priorities, fund research and development (R&D) programs, and address similar S&T issues. Each nation's R&D funding figures are presented in current U.S. dollars in several major R&D

categories. Other R&D funding categories may be found in the chapters on each nation (US, Germany, Japan, India, Australia, UK, New Zealand, and the EU).

- *International Science and Technology Issues: Summary of a Report to the Committee on Science*. Report to Congress, Washington, D.C.: Congressional Research Service, Science, Technology, and Medicine Division, April 20, 1998, 15p.

This report is a summary of a comparative study on international science and technology, prepared at the request of the Committee on Science of the House of Representatives. It provides a digest of analysis and findings on the science and technology policies, civilian research and development funding, and relevant policy issues of 13 countries and the European Union. It also provides a description of why these findings and issues may be of interest to U.S. policymakers, as well as an analysis of issues and concerns about U.S. data collection and information.

- and R. E. Rowberg, *Linkages between Federal Research and Development Funding and Economic Growth*. A Report in the Series Economic Policymaking in Congress: Trends and Prospects. Report for Congress, Washington, D.C.: Congressional Research Service, The Library of Congress, 1992. 19 p.

This report provides information on other forms of "direct" (R&D) and "indirect" (other areas) S&T policies in the United States). The report examines the contribution of Federal R&D to economic growth. It addresses the question about a more direct Federal role in the context of international economic competition. Finally, policy considerations are presented which could affect the relationship between mission agency R&D and economic growth, and the issues surrounding a more direct Federal role.

- McGeary, Michael, "Where Does the Federal Dollar for Basic Research Go?" working paper, submitted to the National Academy of Sciences Committee on Criteria for Federal Support of Research and Development meeting held on March 30-April 1, 1995, in Washington, D.C.

This paper provides information on federally funded basic research. Using NSF 1994 S&T data, the paper discusses who provides the funds for basic research and why, describes which mechanisms are used to provide support, and discusses which agencies and departments conduct basic research and in which areas. It also provides a general overview and breakout of indirect costs paid to universities and other extramural research institutions.

- Merrill, Stephen A., and Michael McGeary, "Balancing the Federal Research Portfolio: Who's Deciding and Why?" working paper, Washington, D.C.: National Research Council, National Academy of Sciences, August 11, 1999.

The authors take issue with congressional claims that the current R&D budgeting process results in a well-balanced portfolio. By examining NSF data, the paper identifies 15 areas of R&D in which funds have declined during the 1990s. The authors note that no one agency is responsible for ensuring that this drop in R&D funding is not harming the national interest. They call for (1) a bottom-up evaluation of these cuts, (2) a more open discussion of national S&T priorities, and (3) principle policymaking bodies to make adjustments to the funding portfolio when there appears to be a serious shortfall in desirable investment.

- National Academy of Sciences. National Research Council, *Evaluating Federal Research Programs: Research and the Government Performance and Results Act*. Washington, D.C.: National Academy Press, February 1999.

The NRC released report recommended that federal agencies develop performance measures for research, and issued "benchmarking" reports comparing the status of U.S. science to other countries for mathematics, materials science and engineering, and immunology. The agencies submitted strategic plans to the Congress in September 1997 and delivered annual performance plans with FY1999 budget justifications.

- National Research Council, *Harnessing Science and Technology for America's Economic Future: National And Regional Priorities*. Washington DC: National Academy Press, 1999.

Report makes recommendations to develop new mechanisms for international research collaboration to advance fundamental knowledge, drawing on the experience of recent years. After the federal government, the academic institutions performing research and development (R&D) provided the second largest share of academic R&D support. The NRC report noted that much of this funding comes from state governments, but is counted as institutional funding because the university has discretion over whether it will be spent on research or in other ways. Industrial R&D support for academic institutions has grown more rapidly than support from other sources since 1980 (i.e., in constant dollars, industrial-financed R&D increased by an estimated 250% from 1980 to 1995, and industry's share grew from 3.9% to 6.9%) (NRC, 1999). More extensive university-industry collaboration on long-term issues of interest to industry could help to alleviate the funding pressures being faced by universities (NRC, 1999).

- National Research Council. *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories*. Washington DC: National Academy Press, 1998.

Each year since 1959, the National Research Council has assessed the programs of the National Institute of Standards and Technology (NIST), and its predecessor, the National Bureau of Standards. Assessments are currently performed by about 150 leading scientists and engineers, equally from U.S. industry and academe, appointed by the National Research Council (NRC), and administered by the NRC's Board on Assessment of NIST Programs. There are currently seven major Panels that assess the major organizational areas: electronics and electrical engineering, manufacturing engineering, chemical science and technology, physics, materials science and engineering, building and fire research, and information technology.

- National Research Council. "International Benchmarking of US Materials Science and Engineering Research," Committee on Science, Engineering and Public Policy. Washington, DC: National Academies Press, 1998.
- Observations on the President's Fiscal Year 1999 Federal Science and Technology Budget, Washington, DC: National Academies Press, April 1998.
- Institute of Medicine, *Scientific Opportunities and Public Needs: Improving Priority Setting and Public Input at the National Institute of Health*, Washington, D.C.: National Academy Press, 1998.

This report examines the way in which NIH sets priorities and provides a few recommendations for improvement. The report states that NIH's objectives should revolve around identifying the public's health needs, extending basic research and. The report recommends that NIH continue to use its current method for criteria setting, but implement a more systematic use and analysis of data sources for input in priority setting. The report also recommends an increased role for NIH's Advisory Committee as well as the establishment of a Public Liaison Office.

- National Research Council, *A New Science Strategy for Space Astronomy and Astrophysics*, Washington, D.C.: National Academy Press, 1997.

This update to the 1991 report, *The Decade of Discovery in Astronomy and Astrophysics*, uses priority-setting methods established in 1991 to provide a strategy for space astronomy and astrophysics. In doing its priority setting, the Task Group on Space Astronomy and Astrophysics, the community (1) concentrated on the scientific objectives rather than the method; (2) prioritized scientific questions according to whole classes of astronomical objects, rather than to individual observing bands; and (3) looked realistically at cost and technical feasibility.

- National Research Council. *Understanding Risk: Informing Decisions in a Democratic Society*. Washington, D.C. National Academy Press, 1996.

- Board on Environmental Studies and Toxicology. "Interim Report of the Committee on Research and Peer Review at EPA." Washington, D.C. National Academy Press, 1995.
- Committee on Criteria for Federal Support of Research and Development, *Allocating Federal Funds for Science and Technology*, Washington, D.C.: National Academy Press, 1995.

The Committee on Criteria for Federal Support of R&D provides an overview of how R&D is defined within the federal government and describes the current process of allocating R&D funds through federal departments and agencies. Based on this information and a literature review, the committee recommends three policy initiatives for allocating federal funds: (1) The President should present an annual comprehensive FS&T budget; (2) the departments and agencies should make FS&T allocation decisions based on clearly articulated criteria that are congruent with those that the Executive Office of the President and Congress use; and (3) Congress should create a process that examines the entire Federal Science & Technology budget before the total federal budget is disaggregated.

- National Research Council. *Science and Judgement in Risk Assessment*. Washington, D.C.: National Academy Press, 1994.
- *Science, Technology, and the Federal Government: National Goals for a New Era*. Washington D.C.: National Academy Press, 1993.

This report recommends tying S&T goals to two overarching principles: (1) The U.S. should be among the world leaders in all major areas of S&T, and (2) the U.S. should maintain clear dominance in scientific fields likely to contribute to substantially important economic, social, or cultural objectives. Further, government should cooperate with the private sector to maintain U.S. leadership in technologies that promise to have major influence on industrial and economic performance and that could lead to new industries, based on principles of cost-sharing, insulation from distributional politics, and stable support.

- National Research Council, Astronomy and Astrophysics Survey Committee, *The Decade of Discovery in Astronomy and Astrophysics*. Washington, D.C.: National Academy Press, 1991.

This report discusses the results of a survey conducted by the Astronomy and Astrophysics Survey Committee of the NRC. The study was commissioned to provide an overview of what is going on in astronomy and to recommend initiatives for the coming decade. The committee was tasked to provide a prioritized list of instruments for the coming decade, evaluate the existing infrastructure, explore the consequences of the computer revolution for astronomy, prepare a popular summary of opportunities for scientific advances in astronomy, and suggest possible areas for developing new observational technologies.

- Presidents of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Federal Science and Technology Budget Priorities*. Washington, D.C.: National Academy Press, 1988.

This report notes that the absence of a coordinated national R&D budget and lack of suitable criteria for making global R&D budget decisions hinders effective use of federal dollars. The report notes that priority-setting within agency missions is adequate and that a pluralistic approach to budgeting has been a strength of the U.S. system. In three classes of activity, however, special attention is needed: (1) initiatives contributing to the science base, (2) initiatives tied to presidential or congressional directives, and (3) major "megascience" projects slated for rapid growth or large pieces of the budget.

- *Risk Assessment in the Federal Government: Managing the Process*. Washington, D.C.: National Academy Press, 1983.

National Institutes of Health. *Setting Priorities at the National Institutes of Health*. Washington, D.C.: Department of Health and Human Services, September 1997.

NIH's Working Group on Priority Setting provides a description of the way that the NIH set's priorities. According to the Group, the NIH provides funding to programs by 1) responding to public health needs 2) following a stringent peer review system and 3) diversifying its research portfolio to include a variety of research. Input into which research programs NIH will pursue depends on the advice of a variety of actors from the extramural science community to Congress and the Administration.

National Institutes of Health. *NCRR. A Catalyst for Discovery. A Plan for the National Center for Research Resources 1998-2003*. Bethesda, MD: Office of Science Policy, NCRR/NIH, 1998.

National Science Board, "Government Funding of Scientific Research," working paper, Washington, D.C.: U.S. Government Printing Office, NSB-97-186, 1997.

The NSB report calls for mandatory priority setting and coordination of federal R&D. Report provides a follow up to its 1997 announcement that NSB would play a larger role in setting national S&T priorities and policy. Separate House and Senate science policy efforts are also described under the FY1999 budget section.

— "Overview: Science and Technology in Transition to the 21st Century," in *Science and Engineering Indicators*, Washington, D.C.: National Science Foundation, 1998.

National Aeronautics and Space Administration. "NASA Performance Plan Fiscal Year 1999." Washington, DC: U.S. Government Printing Office, February 1999.

This GPRA document describes performance measures for FY99 Budget activities.

National Science Foundation. "FY1999 GPRA Performance Plan", Washington, DC: National Science Foundation, January 1999.

— GPRA Strategic Plan FY1997-FY2003. Washington, DC: National Science Foundation, September 1997.

National Science and Technology Council. *National Nanotechnology Initiative: Leading to the Next Industrial Revolution*. February 2000.

-- *Strategic Planning Document - Transportation R&D*. National Science and Technology Council (NSTC) 1995 Strategic Planning Documents, March, 1995.

This summary report of Federal transportation research and development priorities was prepared for the National Science and Technology Council (NSTC) by the NSTC Interagency Coordinating Committee on Transportation R&D and the Office of Science and Technology Policy. The strategic plan reflects the initial efforts of the Committee to assess Federal research and to develop long-term R&D programs integrated across agencies in specific transportation-related areas of common interest. It is based primarily on materials developed by the subcommittees and working groups, working within the framework established by the full committee in its Strategic Budget Guidance report presented to NSTC in April, 1994.

The summary report was compiled from subcommittee submissions by staff of DOT's Volpe National Transportation Systems Center under the direction of Noah Rifkin, Executive Secretary of the Committee and DOT Director of Technology Deployment and by the White House Office of Science and Technology Policy. The subcommittee report contains extensive additional detail concerning agency programs, goals, issues and resources. Efforts of the Committee in 1994, summarized in this

document, focused on identification of perceived R&D gaps and opportunities. They provide the foundation for generation in 1995 of a detailed and comprehensive description of Federal transportation R&D goals, plans, measures, budgets and priorities, including active coordination with other NSTC Committees.

—1998 *Annual Report*, Washington, D.C.: National Science and Technology Council Program Office, 1998.

—1997 *Annual Report*, Washington, D.C.: National Science and Technology Council Program Office, 1997.

Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade*, Washington, D.C.: U.S. Government Printing Office, OTA-SET-490, May 1991.

This study suggests that the criteria used to set priorities for various areas of research lack explicit guidelines, particularly at the highest levels of allocation, leading to widely varying criteria and outcomes. OTA also commented that the lack of a mechanism for evaluating the total research portfolio of the federal government in terms of progress toward many national objectives results in S&T being only loosely tied to needs. Finally, the federal S&T enterprise should seek to include criteria beyond scientific merit and mission relevance when judging the worth of a research program. The report calls for OSTP to disclose the criteria by which federal S&T priorities are set.

President's Committee of Advisors on Science and Technology, Review of the Proposed National Nanotechnology Initiative, November 1999.

— Letter to President, 6 December 1996.

— PCAST Fusion Review Panel, The U.S. Program of Fusion Energy Research and Development, 11 July 1995.

Popper, Steven W., "Policy Perspectives on Measuring the Economic and Social Benefits of Fundamental Science," RAND MR-1130-STPI. Santa Monica, CA: RAND, September 1999.

Press, Frank, "Criteria for the Choice of Federal Support," *AAAS Science and Technology Policy Yearbook 1996/1997*, Washington D.C.: American Association for the Advancement of Science, 1997, pp. 171-178.

Frank Press, chair of the committee that published a report entitled *Allocating Federal Funds for Science and Technology*, builds upon and reacts to ideas put forth in the report. The article states that we need to make the idea of a federal science and technology budget a reality, one that not only contains budget numbers and definitions but also provides a process for upgrading the S&T portfolios of agencies by forcing trade-offs. Appropriations for this budget can be debated within a new subcommittee created for the specific purpose of evaluating the FS&T budget. This type of structure, however, has come under criticism for several reasons (1) it might make the FS&T budget vulnerable during times of budget deficits, (2) it may result in a decrease in the overall budget pool for S&T, and (3) it may create conflict within the science community to increase the budget instead of complying with constrictions, and (4) because the NAS report is itself viewed biased in favor of federal labs and universities.

Robinson, David Z., "Think Twice before Overhauling Federal Budgeting," *AAAS Science and Technology Policy Yearbook 1996/1997*, Washington D.C.: American Association for the Advancement of Science, 1997, pp. 217-224.

This article disagrees with the ideas proposed in the NAS report, *Allocating Federal Funds for Science and Technology*, calling an FS&T budget structure conceptually and practically wrong. Robinson continues to state that trade-offs should not be made between categories of FS&T investment but between S&T and other expenditures within a federal agency. He continues to argue

that mechanisms are already in place to review specific areas of R&D duplication. Robinson recommends that, instead, policymakers should determine the appropriate level of support by linking FS&T programs to national goals while making trade-offs between current and future needs.

Saunders, Kenneth V. *et al.*, *Priority-Setting and Strategic Sourcing in the Naval Research, Development, and Technology Infrastructure*. Santa Monica, CA: RAND, 1995.

This report suggests ways in which the Dept. of the Navy might realize more value from its increasingly constrained research, development, and technology (RD&T) dollars. The study was motivated by the Navy's immediate policy needs in connection with the 1995 round of Base Realignment and Closure (BRAC) and its longer-term need to make the best use of its resources. Suggestions are presented in three parts. First, the authors develop and apply a framework for setting funding priorities in the Naval RD&T infrastructure. Second, the authors discuss alternative RD&T procurement arrangements that are seeing increasing use in the private sector and that have been used in various parts of the government. These are commonly called "smart buying," but the authors use the term "strategic sourcing." Third, the authors present a speculative combination of the priority-setting and strategic-sourcing considerations of the first two parts. Using a reinterpretation of the orthogonal plot developed earlier in the report, it suggests a way to help determine which parts of the Naval RD&T infrastructure are best suited for alternative procurement arrangements. It also suggests a way to determine which facilities might be involved.

Science and Government Report, Mar. 1, 1997.

The Vice President for Research at the University of Michigan, proposed a high-level public/governmental commission to assess "the rationale for investments in research' by...governments, industry and universities...the division of labor among academic, industrial and government laboratories; criteria for setting levels of R&D support, and the implications of current long-term spending projections for research."

Shapley, Willis H., *The Budget Process and R&D*. Washington, D.C.: Carnegie Commission on Science, Technology, and Government, April 1992.

This report describes and discusses the federal budget process with a focus on R&D. Shapley proposes and addresses several concerns that have arisen in creating a federal R&D, including (1) setting priorities and achieving balance, (2) the use of budget data, (3) the stability and continuity of the current budget process, and (4) the fragmentation of R&D in the budget review process in OMB and Congress. Shapley states that (1) R&D funding for programs should not be pitted against each other but rather against the overall federal budget; (2) a comprehensive comparable databank on R&D budgets should be established, as proposed in a 1988 report of the Senate Budget Committee; (3) a partial rather than immediate implementation of a two-year appropriation cycle is more politically saleable and (4) subcommittee hearings for R&D should not be done by a separate committee, because this could make R&D agencies more vulnerable to arbitrary reductions. Finally, Shapley states that there is a significant shortfall in the R&D budget in meeting important needs and grasping important opportunities. The report states that the nature of R&D makes it a necessity to increase funding in certain S&T areas to keep pace with advances; however, this is difficult to accomplish in a deficit-ridden budget.

Smith, Philip M., and Michael McGeary, "Don't Look Back: Science Funding for the Future," *Issues in Science and Technology Online*, Spring 1997.

This article stresses that evolving national priorities and budget constraints call for a new approach to federal spending. Corroborating the NAS report, *Allocating Federal Funds for S&T*, the article calls for the development and use of a federal S&T budget. It calls on the OMB and OSTP to implement

an annual FS&T analysis as a part of the normal budget review. The authors state that using this analysis would help the most productive programs under a tight budget while strengthening the case for making larger investments in R&D.

Teich, Albert, "Choosing Among Disciplines," *AAAS Science and Technology Policy Yearbook 1991*, Washington, D.C.: American Association for the Advancement of Science, 1991, pp. 41-45

Teich discusses the conflicting perceptions that have arisen as a result of priority-setting discussions. The article addresses (1) who should do the priority setting, (2) who would use the results and how, and (3) what the outcomes of the process would be. The article also states that despite the concerns that have arisen, the budget process would benefit from the change. Furthermore, incorporating priority-setting methods based on technological merit, scientific merit and social merit would greatly improve the process.

The Government Performance and Results Act, P.L. 101-189 and P.L. 100-456

Require the Department of Defense (DOD) and the Office of Science and Technology Policy (OSTP) to identify priorities for critical dual-use technologies for national security and economic prosperity.

Thomas, Eleanor. Strategic Planning at the National Science Foundation. Arlington, VA: National Science Foundation, July 1996.

U.S. Congress, The Senate FY1999 VA/HUD/Independent Agencies Appropriations Report, Washington, DC: Congressional Printing Office, 1999.

The Senate FY1999 report called on NSF to identify quantifiable goals for research. The appropriations act, P.L. 105-276, gave OSTP and OMB authority to seek the NAS study, as in S. 2217 (in the 105th Congress), but did not include the related provisions.

— House Majority Leader Report. Washington, DC: Congressional Printing Office, 1999.

The House Majority Leader issued a report "rating" the FY1999 plans. The House Committee on Government Reform and Oversight and the Senate Committee on Governmental Affairs held hearings on implementation.

— House of Representatives, Committee on Science, *Unlocking Our Future: Toward a New National Science Policy*. Washington, DC: Congressional Printing Office, 1998.

Recognizing that choices about funding R&D must be made in the face of limited federal resources, this report says that priorities for spending on science and engineering will have to be set. Because of its unique role, fundamental research in a broad spectrum of scientific disciplines, administered through the peer review process, should receive priority for federal spending. A "sharp eye" should be kept on possible downstream applications for such research. Mission-oriented research should continue to fund highly relevant, noncommercial, long-term research.

— *The Government Performance and Results Act*, P.L. 103-62. Washington, DC: U.S. Congress Printing Office, 1993.

GRPA requires agencies to define long-term goals, set specific annual performance targets, and report annually on performance. Legislative language noted the difficulty of quantitatively measuring some program outputs and allows alternatives.

Vonortas, Nicholas S., "Prioritizing Long-Term, Strategic R&D Projects in the Public Sector," Washington, D.C. Center for International Science and Technology Policy & Department of Economics, The George Washington University, paper submitted for the National Science and Technology Council's Summit, Innovation: Federal Policy for the New Millennium, to be held on November 30 and December 1, 1999.

This paper proposes a technology-option approach in choosing long-term, risky R&D investments. According to the author, this methodology explicitly accounts for the uncertainty of long-term R&D and captures the value in terms of opening up opportunities for private-sector investment in new technologies. The paper also argues that this approach has the potential of eliminating R&D political battles by focusing on strategic R&D project selections.

Wells, William G., Jr., *Working with Congress: A Practical Guide for Scientists and Engineers*, Washington, D.C.: American Association for the Advancement of Science, 1992.

This book introduces scientists and engineers to the congressional appropriations process.