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REPORT BY THE

Comptroller General

OF THE UNITED STATES

Assessing The "Output" Of Federal Commercially Directed R&D

GAO was asked how the results of federally financed research and development spending could be measured

To assess the output of Federal commercially directed R&D spending it is necessary to understand the role played by R&D in embodying a laboratory result in a commercially acceptable product or process

The process is complex and the approach to assessing the output of commercially directed R&D must recognize and analyze the interactions occurring between R&D spending and other types of Federal incentives necessary to achieve program goals

GAO studied the Department of Energy's Solar Photovoltaics program to illustrate the complexities The report suggests a number of questions that ought to be asked of R&D programs contemplated or currently running

UNITED STATES GENERAL ACCOUNTING OFFICE

PAD 79-69
AUGUST 27, 1979

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D C 20548

B-164912

The Honorable Lloyd M. Bentsen, Jr.
Chairman, Joint Economic Committee
Congress of the United States

PDT00700

Dear Mr. Chairman:

As part of the Special Study on Economic Change, the Joint Economic Committee Chairman asked GAO how the output of federally financed research and development (R&D) could be measured to improve resource allocation decisions. This report describes an approach for assessing federally financed commercially directed R&D spending output--an R&D activity which has the greatest potential for output measurements useful for improved resource allocation decisions. It also addresses the conceptual problems and available methods of obtaining consistent and comparable measures needed to improve allocation decisions.

The question addressed by this report concerns many legislators. Accordingly, we are today sending this report to several other interested congressional committees.

Copies are also being sent to the Director, Office of Management and Budget; the Secretaries of Energy; Health, Education, and Welfare; Defense; Housing and Urban Development; Transportation; and Agriculture; the Office of Science and Technology Policy; the Administrator, National Aeronautics and Space Administration; and the Director of the National Science Foundation.

Sincerely yours,

Elmer B. Staats

Comptroller General
of the United States

COMPTROLLER GENERAL'S
REPORT TO THE
JOINT ECONOMIC COMMITTEE

ASSESSING THE "OUTPUT" OF FEDERAL COMMERCIALLY DIRECTED R&D

D I G E S T

TNT00700

The Joint Economic Committee, as part of its Special Study of Economic Change, requested that GAO address how results of federally-financed research and development can be measured. The Committee noted that a number of studies have discussed the relation of R&D to such areas as economic growth and productivity, and asked GAO to concentrate on intermediate R&D outputs (such as new products and their value) more closely related to specific expenditure of Federal funds. The request stated that improved measures of R&D output would be particularly useful in improving the allocation of resources among alternative projects, but recognized that the subject to be discussed was quite broad.

Attempts to develop measures of output which can be used consistently among Federal R&D projects must try to deal constructively with the following problems:

--R&D expenditures are undertaken for a variety of reasons. Some attempt to develop new knowledge; others are directed to meeting needs, such as national defense, for which there is no commercial market; and still others are directed at lowering the cost of products which will be purchased by consumers or which are used in the manufacture of products purchased by consumers.

--R&D results are diverse. Some projects produce revolutions; others produce nothing.

--R&D is generally speculative. Not much is known in the embryonic stages of a project about what will happen. Even years later, controversy over accomplishments may exist.

--The economic effects of R&D are not well understood, even after years of study.

--Most important, R&D is only one "input" into a complex process of search, discovery, innovation and commercialization of new ideas.

Given the nature of these problems, there is no possibility of eliminating the role judgment plays in the allocation of the Federal Government's resources in the R&D area. However, it is possible to improve the quality of the analytical information available to executive branch officials and Congress on a systematic basis when they make judgments about which projects best serve the public interest.

THIS STUDY'S FOCUS ON COMMERCIALLY DIRECTED R&D

This report concentrates on one type of federally financed R&D in which progress in improving the allocation of resources is most likely to be made--Federal commercially directed R&D. Commercially directed R&D programs are growing in importance as a proportion of Federal R&D spending, mainly because of the priorities given to developing alternative energy sources and to the efficient use of exhaustible energy resources.

One goal of commercially directed R&D projects is adoption and marketing by private-firms of goods or services embodying the results of federally financed R&D. The Federal Government invests in these projects because:

--Social returns are believed to be positive, but;

--perceived private returns are insufficient to justify the investment; and

--uncertainty regarding commercial success makes today's payoff too low to justify the investment.

Commercially directed R&D programs are implicitly or explicitly justified on the grounds that results will ultimately have an economic value. The tie to market processes provides the key for developing a consistent measure of R&D activity, because markets value diverse goods and services by a single monetary standard. If reliable market-based valuation measures can be developed, they can be used in allocating resources both among R&D projects with economic outputs and between R&D projects and other Federal programs providing outputs with economic value.

CONCEPTUAL FRAMEWORK

The conceptual framework for appraising Federal commercially directed R&D that we suggest draws heavily on professional literature which deals with the process of innovation in our economy. The framework is based upon the following two principles.

--Federal R&D contributions to the innovation process need to be evaluated in the context of all other factors affecting commercial acceptance of innovation.

--Estimates of value to consumers, which will result when products embodying federally financed R&D expenditure come on the market, can be used to calculate the rate of return on resources invested in Federal R&D.

Research and development is useful for overcoming scientific and some technical barriers. But there are other nonscientific barriers that impede delivery of an R&D result into widespread commercial use. To achieve market acceptance of an R&D result, all institutions involved in the manufacturing, marketing, distribution and end use of the technology must be induced to accept its usefulness. A mix of program options including financial assistance, procurement, tax credits, etc., may be necessary to overcome these barriers since they cannot be overcome by R&D spending alone. Policy inputs and R&D spending all contribute to the realization of a commercial result. A valid but complex approach to measuring the output of Federal commercially directed R&D should model impediments to commercial success and the

Tear Sheet

inputs applied to mitigate them. The market price of the products resulting from R&D and the value of the products to consumers should be estimated. Then one of two measurement approaches could be used in measuring the output of the Federal R&D expenditures:

--A total input-output approach where the measured output is compared with total program costs which consist of R&D costs and all other program input costs; or

--An incremental product approach where the marginal output of R&D spending given levels of all other program inputs is compared with R&D costs.

The second of these measured approaches is the most desirable. With a budget constraint, R&D expenditures should be allocated to R&D projects in which the value received per dollar invested in R&D expenditure is the highest.

USEFULNESS OF THIS FRAMEWORK

In practice, it is very difficult to obtain the data needed to apply the framework in a literal way. For example, the price of output in the future resulting from today's R&D expenditure is difficult to estimate with any degree of certainty, and the value to consumers of this output depends upon the price of other goods and services which are similarly difficult to measure. Also, determining the contribution of R&D spending is very difficult because lead times are long between R&D expenditures and market acceptance of the technology and R&D is but one contributing factor to the output or innovation result. These limitations in data availability due to uncertainty and other factors suggest that the usefulness of the framework lies primarily in its ability to provide guidance in asking the right questions about R&D projects on a systematic basis.

The report uses the Department of Energy's solar photovoltaic program to illustrate how the framework for analysis suggested here can be used to develop useful information for the analysis of R&D spending. This example shows the importance of identifying and attempting to quantify the regulation, tax, and other factors that affect the value of Federal R&D spending.

The report also identifies 11 questions which incorporate the point of view in the framework. If they are answered carefully on the basis of the best information and estimates available, GAO believes that the information which would become available to policymakers would substantially improve the ability of agency officials and of Congress to make informed judgments about Federal expenditures for commercially directed R&D expenditures.

AGENCY COMMENTS

We obtained informal comments from the National Science Foundation, Department of Energy, American Association for the Advancement of Science, and the Congressional Research Service. Those commenting thought that the framework presented here represented very good progress. Some, however, questioned the practical applicability of the framework in view of the lack of data, uncertainty and multiple objectives involved in Federal R&D activities. As the preceding discussion makes clear, GAO recognized that the framework which we discuss cannot be implemented literally and that allocation of resources in the commercially directed R&D area necessarily involves judgments about many complex factors. However, we also believe systematic effort to gather the type of information suggested here would help executive branch officials and the Congress make their judgments on the basis of information of better quality than is now generally available.

Contents

ABBREVIATIONS

DOE	Department of Energy
OPEC	Organization of Petroleum Exporting Countries
R&D	research and development

CHAPTER 1

INTRODUCTION

The Joint Economic Committee as part of its Special Study of Economic Change, requested that GAO address how results of federally financed Research and Development (R&D) could be measured. The Committee noted that a number of studies have discussed the relation of R&D to such areas as economic growth and productivity, and asked GAO to concentrate on intermediate outputs (such as new products and their value) more closely related to specific expenditures of Federal funds. The request stated that improved measures of R&D output would be particularly useful in improving the allocation of resources among alternative projects, but recognized that the subject to be discussed was quite broad.

The Committee's question is important. It is a derivative of a question asked with increasing frequency about all types of Government spending: What are taxpayers getting for their money?

Answering the question for research and development is difficult because:

--R&D results are diverse. Some projects produce nothing while others produce revolutions. The results differ in kind and in magnitude.

--Much R&D activity is uncertain. In the very early stages, little is known about what will happen, and even years later there is controversy over what has been accomplished.

--The economic effects of R&D are not completely understood, even after years of study.

--R&D is but one "input" into the complex process of search, discovery, innovation, and commercialization of new ideas.

This report presents a means for assessing the output of commercially directed Federal R&D spending. In these situations the Federal Government is the principal source of financing in the initial stages of development, may or may not be a secondary source in ensuing stages, and probably is not a major purchaser of final R&D results. The result of this type of Federal innovation effort is expected ultimately to be adopted commercially and produced, marketed, distributed, and consumed in the private sector.

Examples include development of a resource recovery system for preparing shredded domestic solid waste as a supplementary fuel in a boiler furnace (Department of Health, Education, and Welfare); development of a low cost, lightweight multichannel transceiver to be used by civilian law enforcement personnel (Law Enforcement Assistance Administration); and many of the exotic and solar energy alternative technology programs administered by the Department of Energy, such as coal gasification and photovoltaics. The results of these research programs are expected to be adopted by private firms and brought to commercial viability in the private sector following Federal involvement. 1/

Federal commercially directed R&D spending is an activity with a good potential for output measurement useful for improving the budgetary resource allocation process. (This report does not pertain to R&D programs whose costs are justified on the grounds that they produce public goods.) There is little doubt that basic research (as an end in itself) creates a highly beneficial scientific or technical base on which the Nation can rely for future applied or developmental purposes Allocating R&D spending to social and defense-related, or certain aerospace research involves political decisionmaking--a process replete with value judgments. Such allocation activity may not have clearly identifiable "outputs" or, if identifiable, the outputs cannot be measured on an economically consistent basis because they are not valued in the marketplace.

If improvements are to be made in allocating R&D dollars efficiently, they most likely will be made where program results can be measured consistently. Commercially directed R&D programs are implicitly or explicitly justified on the grounds that results will ultimately have an economic value, in addition to other social benefits. Measures of potential or actual value are a meaningful measure of output. They can be consistently used to allocate resources both among R&D projects with economic outputs and between R&D projects and other Federal programs providing outputs with economic value. Such R&D programs are growing in importance as a proportion of Federal R&D spending, mainly because of the priorities given to developing alternative energy sources and to the efficient use of exhaustible energy resources. Furthermore, unlike defense--or some aerospace-related R&D spending--

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1/C. Williams, E. Milbergs, and R. Quick, "Preliminary Assessment for Designing Experiments Using Federal Innovation Process," Stanford Research Institute, Menlo Park, Calif., Apr. 1977.

commercially directed R&D programs do not operate in a closed system of Government management, funding, and incentive control because the Government is not the sole end user. The private sector is the main end user.

The appropriate Federal role when the private sector or a portion of it is the principal end user is disputed, and this increases the importance of wisely allocating funds to such projects.

Thus, we have emphasized commercially directed research and development because:

--Other types of Federal research and development, though quite important, do not produce results which are economically measurable on a consistent basis.

--If improvements are to be made in the R&D resource allocation process, they will most likely be made if the output can be measured or estimated from program inception through product or process innovation and diffusion.

--Commercially directed research and development is growing in importance as a percent of total Federal R&D spending.

--Because the results of commercially directed research and development produce private benefits at public expense, resource allocation decisions for these projects become <u>very</u> important.

This report makes several points:

1. Many have attempted to measure either the contribution of specific R&D innovations or the aggregate impact of innovation. We believe that these methodologies are adaptable to the planning and monitoring of Federal R&D spending.

2. Years may elapse between R&D spending and an innovation's commercial success because numerous economic, social, and technical impediments may prevent its market penetration. A framework for assessing the results of Federal R&D spending must explicitly recognize these obstacles because research and development (R&D) can contribute to economic output only when combined with other incentives or mechanisms designed to overcome nonscientific or nontechnical barriers.

3. We distinguish between measuring an output in economic <u>value</u> terms (such as dollars of benefits) and in <u>nonvalue</u> terms (such as the number of patents, or production figures, or number of publications or citations). Outputs may be valuable in the sense of having importance, but they cannot be measured in value-based terms.

4. Until Federal R&D results have an end use, they cannot be consistently valued. If results (outputs) cannot be valued, they cannot be consistently compared with other outputs--and hence there can be no adequate basis for improving resource allocation decisions.

5. Federal R&D contributions cannot be precisely measured if the program is even moderately complex. The measurement must fully account for the impact of other policy inputs into the innovation process. The measurement must also treat the innovation in terms of its <u>marginal</u>, or incremental, outputs when combined with other inputs in an "innovation production function." Moreover, any framework for assessing outputs must be adapted to a specific program before it can be useful.

Given the nature of these problems, we believe there is no possibility of eliminating the role judgment plays in allocating the Federal Government's resources in the R&D area. Lack of data and uncertainty about outcomes make a literal application of a hard and fast methodology impossible. However, we believe it is possible to improve the quality of the analytical information available to executive branch officials and Congress on a systematic basis when they make judgments about which projects best serve the public interest.

Chapter 2 reviews the innovation process, drawing upon other analyses of R&D outputs.

Chapter 3 discusses R&D program goals, distinguishing between value-based goals and nonvalue-based goals.

Chapter 4 reviews the main value-based methods used to measure outputs of R&D spending. All were developed to measure the impact of R&D after the fact, using data recorded after the innovations had diffused into the economy. We suggest that some of these methods be adapted to plan R&D programs and to monitor the programs' progress, thus improving the efficiency of Federal R&D spending.

Chapter 5 applies our framework to the Department of Energy's (DOE) solar photovoltaics program. We have not evaluated or reached any conclusions on how well DOE has planned or administered the program. Rather, we have used this example to show how Federal research and development is meant to produce certain outputs and how outputs might be measured.

The photovoltaics program was chosen because its goals relate mainly to reducing the cost of producing an existing, well-defined, and easily measured product--electricity. Even so, the program is quite complex, since there are other inputs into the innovation process. Research and development alone is insufficient to achieve the program's goals. Moreover, achieving program goals is, at best, years away. By then, prices of alternative energy sources could greatly affect the value of the program's achievements.

Though a hard and fast methodology for measuring R&D output is not developed in this report, economic theory and analysis often pose worthwhile questions and a systematic way of approaching issues. Such an approach is presented in chapter 6 as a series of questions which ought to be asked of current and contemplated Federal R&D programs.

CHAPTER 2

THE INNOVATION PROCESS

Innovation is the process by which inventions or new ideas are redesigned and embodied in various outputs until something of commercial value--an innovation--is produced. Diffusion is the process by which the innovation achieves widespread commercial acceptance. Economic benefits begin with innovation and continue until the innovation becomes obsolete. In the innovation process, the Federal role may be paramount to success or failure.

A study by John Enos examining 46 major industrial innovations found that the average period between invention and innovation was 13.6 years. 1/ The interval varies considerably among innovations; for example, the flourescent lamp took 79 years while streptomycin took only 5. 2/ A lag exists because there are numerous economic, social, and technological barriers to an invention's commercial success. The less formidable and the fewer barriers there are, the sooner diffusion occurs.

Numerous outputs occur between invention and innovation. In a study Albert H. Rubenstein categorized the relationship of R&D spending to the production of outputs that contribute to productivity growth and confer social and economic benefits in four stages: 3/

1. Immediate outputs, those directly attributable to the R&D process. These outputs appear close in time to a research and development outlay Examples are ideas presented in journal articles or other publications and patent applications.

1/John Enos, "Invention and Innovation in the Petroleum Refining Industry," The Rate and Direction of Innovative Activity, NBER, 1962.

2/Nathan Rosenberg, Perspectives on Technology, Cambridge, University Press, Cambridge, Mass., 1976, pp. 69-70.

3/Albert H. Rubenstein, "Some Observations on the Effectiveness of Federal-Civilian Oriented Research and Development Programs," in Joint Economic Committee Print, 94th Cong., 2d sess., Oct. 29, 1976, Priorities and Efficiency in Federal Research and Development - A Compendium of Papers, pp. 46-64.

2. Intermediate outputs, those used by social subsystems to produce social and economic benefits. Examples are the adoption of an energy supply invention that results in reduced costs of energy production relative to some baseline state of technology.

3. Preultimate outputs are the commercially viable embodiment of immediate and intermediate outputs. Examples include economically competitive innovations which, at a reduced cost or with increased reliability or both, satisfy some end use, such as staying warm, staying healthy, or getting from one place to another. It is the value of these outputs which provide a basis for assessing R&D results.

4. Ultimate outputs are preultimate outputs that contribute to the quality of life. Examples include better health, better material well-being, or improvement in the quality of life. 1/

The process of R&D spending has a beginning, a middle, and an end, but feedback within and among the stages occurs continuously. The important point is that the inputs of R&D result in outputs which, through time (or during the innovation process), are continuously embodied in subsequent outputs until something of economic significance is or is not produced.

Some outputs are easily identified; others are not. Immediate outputs are easily identified and are not likely to be overlooked. Furthermore, they can be measured in non-value-based terms; for example, patent applications, journal articles, and scientists employed. But outputs at whatever stage cannot be valued in a way that allows policymakers to determine their comparative worth. Since a consistent comparison cannot be made, the merits of immediate outputs produced by R&D project A cannot be compared with those produced by R&D project B.

Cost reduction is a good example of an intermediate output. In some cases a new idea or an invention adopted by firms and produced under factory conditions replaces a more costly product. Here engineering and perhaps remaining scientific problems are identified and overcome. In other cases the innovation reduces the manufacturing cost of an existing commercial product.

1/Rubenstein, op. cit., pp. 46-64.

Inducements designed to achieve the pricing of intermediate outputs at levels that are economically attractive to potential end users may be necessary to facilitate the adoption of a federally funded R&D result. When this happens, intermediate outputs become economically significant and move into the preultimate output stage. R&D results that can be converted, via inducements, into preultimate outputs depend on R&D expenditures and on overcoming various supply and demand impediments to market penetration.

Along the output continuum several points are noteworthy. The closer in time outputs occur to the expenditure of R&D funds, the easier they are to identify, measure, and directly relate to the R&D expenditure <u>but</u> the harder they are to value on a comparative basis. The farther away in time outputs are from R&D expenditures, the easier they are to value, but the more tenuous the association between the R&D expenditures and the value of the outputs. Also the farther the outputs are from the expenditures, the less certainty there is that the measured outputs constitute the total product of the innovation effort, since some outputs are unintended and difficult to identify.

Intended outputs must achieve economic significance to be valued economically. If they cannot be valued, they cannot be compared with their costs in a standard cost benefit analysis. Generally, consistent output measures are not obtained until the results of an innovation program have achieved market acceptance or good estimates of market results are achievable before the fact.

Nathan Rosenberg, a noted economist in this field, suspects that the innovation lag--how long the original idea takes to become commercially embodied and cause subsequent output--has more to do with the social and political environment than with overcoming scientific or technological hurdles. This is particularly true for the Federal innovation process.

<u>THE FEDERAL INNOVATION PROCESS</u>

This study concerns measuring the output of commercially directed Federal R&D programs whose ultimate goal is transfer--commercial adoption and marketing. <u>Programs whose costs are justified on grounds that they produce public goods were not considered</u>. Though commercially directed R&D programs are not devoid of public goods aspects, the rationale for such programs should be to achieve outputs with economic significance.

Federal commercially directed innovations are those that would either not be undertaken or not be undertaken in a timely fashion, but are believed to be in the public interest. The reasons for this include the perception that returns are insufficient to justify the risk of private investment, and the perceived uncertainty about commercial success which makes today's risk-adjusted payoff too low to justify the investment.

In our opinion, a valid but complex approach to measuring the output of Federal commercially directed R&D should be to model the impediments to commercial success and the inputs applied to mitigate them, and to identify the immediate, intermediate, and preultimate outputs. Two measurement approaches are available:

1. A total input-total output approach, in which the measured output is compared with total innovation program costs.

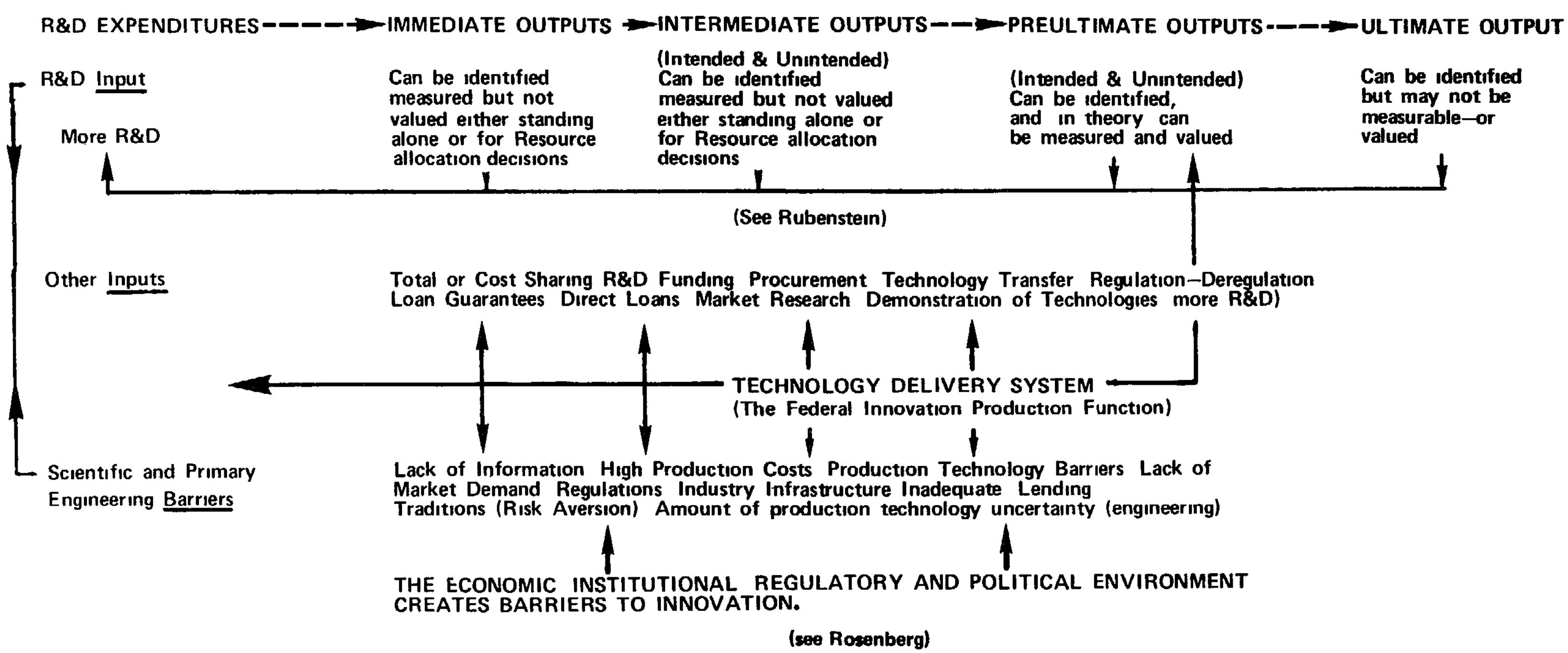
2. A marginal product approach, in which the marginal output of R&D, given levels of all other inputs, is compared with R&D costs.

Regardless of approach, the framework must identify all inputs and specify the interactions among them. Studies of interactions are important even in a total input-total output approach, because the desire to allocate R&D funds among the most productive projects should be matched by a similar desire to allocate other resource inputs efficiently. In economic terms, this means that inputs should be applied during production to the point when the ratio of their marginal outputs to their unit costs is identical (that is, to the point when a dollar of input A or B produces the same additional output).

Figure 1 depicts the Federal innovation process. The complexity of the immediate through ultimate output continuum depends on the economic, institutional, regulatory, and political environment existing during the innovation's life. Besides scientific or engineering constraints, there are other impediments to achieving ultimate goals. These are reduced or eliminated by applying research and development and other inputs to each constraint, and thus producing innovation outputs. In theory these outputs are measurable for resource allocation purposes beginning at their preultimate stage and carrying through to diffusion. Ways of measuring the output of R&D spending are discussed in the next section.

Figure 1

THE INNOVATION PROCESS



The impediment-incentive relationships in the Federal innovation process are described in an article by Arthur A. Ezra as a "technology delivery system." 1/ The system includes all institutions required to transfer the results of federally sponsored research and development to the marketplace. Such institutions include lenders, local and State government regulatory bodies, labor unions, architects, equipment manufacturers, builders, etc. Before the technology can be transferred, all institutions must accept its viability.

Incentives include education programs designed to influence producers and consumers, financial assistance, procurement, tax credits, grants, relaxation of regulations, more R&D spending, and others.

Within a technology delivery system:

1. Incentives may need to be applied to each system component.

2. Different components require different incentives.

3. Information on the process needs to be compiled in a manner suitable for evaluation.

4. All components must work if technology utilization is to occur on a self-sustaining basis. The performance of particular incentives can be evaluated only when the total system is working. No one incentive can produce the desired result.

5. The Federal agency responsible for advocating use of the technology should assume responsibility for (a) identifying all system components, (b) devising incentives to activate each component, and (c) monitoring results to ensure effectiveness. If a required component does not exist, it must be created. 2/

Crucial to a decision on how to measure Federal R&D output is an understanding of the Federal innovation process;

1/Arthur A. Ezra, "Technology Utilization: Incentives and Solar Energy," Science, Feb 18, 1975, pp. 707-713.

2/Ezra, op. cit., pp. 707-713.

the role R&D plays in the process; and the institutional, social, economic, and political environment in which inventions or ideas are sent from the laboratories to the marketplace.

Economists speak not of research and development or labor or capital output but of their marginal products. The marginal product of an input is generally expressed in relation to its application with another input to the production of an output. Thus, we speak of the marginal product of labor at a given level of capital input. As labor is given more capital to work with, its marginal product increases, up to a point. On the other hand, if labor has no capital to work with, it might not produce anything. The analogy to a Federal innovation production function is useful. Research and development alone cannot produce innovation outputs. Research and development must be combined with other inputs in a technology delivery system to transfer technology and therefore produce an output with economic value. Output measurements must consider all interactions between the inputs.

CHAPTER 3

VALUE- AND NON-VALUE-BASED INNOVATION PROGRAM GOALS AND THEIR IMPLICATIONS FOR INFORMED RESOURCE ALLOCATION DECISIONS

A means of assessing the output of Federal R&D spending must incorporate goals expressed in terms that lend themselves to analysis and incorporate relatively clear-cut links between immediate, intermediate, and ultimate program goals. Most Federal R&D program goals, however, are not expressed in terms that can be analyzed in ways essential to improving resource allocation decisions.

For purposes of analysis, statements of goals and objectives should:

1. Identify intended benefits, including expected levels of attainment;

2. Identify recipients of unavoidable adverse consequences or unintended benefits;

3. Include important qualitative aspects, even though measuring degrees of attainment may be difficult; and

4. Consider multiple objectives that may be complementary or conflicting. 1/

Generally, desired accomplishments are expressed as program goals. For example, the overall DOE solar energy program goal is

> "* * * to stimulate the development and introduction at an early date of economically competitive and environmentally acceptable solar energy systems." 2/

1/"Evaluation and Analysis To Support Decisionmaking," U.S. General Accounting Office, PAD-76-9, revised Sept. 1, 1976, p. 14.

2/Department of Energy, Fiscal Year 1979 Congressional Budget Request, vol. 1, "Energy - Operating Expenses and Capital Acquisition," Jan. 1978, p. RTSO 1 of 38.

The two key phrases as they affect output are "economically competitive" and "at an early date." The goal is not nearly specific enough for making improved resource allocation decisions. None of DOE's expected program results are truly value based, though the overall goal clearly implies that something of economic value will be produced.

The individual DOE solar program goals generally describe activities rather than outputs. Consequently, they are non-value-based because there are no value-based or quantity dimensions to compare with a standard or with alternative programs. For example, if one goal of the program is to improve the reliability of a solar photovoltaic device, what constitutes success? An improvement of 20, 100, 500 percent? What kinds of cost reduction are projected? What are the implications of cost reduction for market acceptance? For example, the Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978 (P.L. 95-590, Nov. 4, 1978, 92 Stat. 2513) establishes an installed system cost goal of $1 per peak watt by 1988, but whether the market will accept this cost is uncertain.

Other non-value-based measures include number of patents, production figures, and number of skilled or experienced workers trained. Though all these are important in tracking a program's accomplishments, they are not useful indicators when allocating resources to particular R&D projects. For example, patents are dissimilar because some are extremely valuable and some are worth little. They could be added together only if homogeneity were assumed; i.e., 10 patents in solar photovoltaic equal 10 patents in wind energy. But is it meaningful to compare the production of 1,000 solar cells with 1,000 windmills, given only production data? Even though they are usually more easily identified and measured, non-value-based measures cannot be consistently compared from program to program.

It is tempting to compare today's funding levels for the various solar technologies with changes in the rate at which solar energy would be substituted for fossil fuels (displacement) to arrive at measures of comparative cost effectiveness. This is not very useful because:

1. Funding may continue well beyond the current year and diffusion may continue beyond some target displacement goal year.

2. Annual expenditures do not provide a good indication of total expenditures contemplated to achieve a given displacement level by a certain year.

3. Budgeted research and development in any year will not achieve the desired goal, and it is unlikely that total R&D spending alone will achieve the desired result. Yet R&D results must be realized to determine the cost and the additional incentives required to achieve the desired results.

4. While displacement rates are comparable, the significance of displacing a quad of fossil fuel by the year 2020 is not clear.

5. Displacement rates should be compared with each other only on a life cycle cost basis. This is now impossible, since costs are a major uncertainty in all solar technologies and some uses are likely to be more expensive than others.

Furthermore, without a value for solar energy output, it is not possible to say whether any of the alternative techniques are cost effective.

A more direct link between cost reduction goals and ultimate program goals improves the comparison between such goals and actual results. This occurs when the implications of achieving a given cost reduction by a certain time are clearly related to the expected amount and value of output produced in satisfying ultimate program goals.

The link might be expressed as follows: Achieving cost reduction by a factor of 50 over today's costs by year Y will result in commercial availability in certain applications and is expected to result in displacement of Z percent of alternative exhaustible energy supply use and have a value of $X due to reduced energy consumption costs and environmental effects.

CHAPTER 4

SPECIFIC VALUE-BASED MEASURES

OF THE OUTPUT OF R&D SPENDING

Previous chapters have discussed differences between value-based measures and non-value-based measures of output. For commercially directed Federal research and development, value-based output measures should be used to improve resource allocation decisions because non-value-based output measures cannot be compared with one another consistently. This chapter discusses ways to measure the output of R&D spending.

Thus far, attempts to measure the effects of R&D spending have used two general approaches--the economic surplus approach and the aggregate economic approach. For reasons explained below, we believe that the former holds more promise for planning and for consistently measuring R&D output.

THE ECONOMIC SURPLUS APPROACH

Surpluses which accrue to buyers are usually distinguished from surpluses which accrue to sellers. 1/ "Consumer surplus," an economic impact concept, measures a consumer's benefits due to the availability of a new product or a reduced price of an existing product. 2/ Economists have used this concept to measure the social costs of monopoly (which

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1/For a survey of economic surplus, see J. M. Currie, J. A. Murphy, and A. Schmitz, "The Concept of Economic Surplus and Its Use in Economic Analysis," Economic Journal, vol. 81, Dec. 1971.

2/Technically, consumer surplus is a concept describing the difference between what a consumer would pay for a given quantity of a commodity and the amount actually paid. It arises because markets clear, in theory, at the price tendered by the lowest bidder that is consistent with exhausting the available supply at that price. All participants pay the market clearing price despite the fact that some would be willing to pay more. In the case of an R&D result, a first approximation to estimating consumer surplus is to multiply the quantity purchased by the additional amount that the consumer would have to pay to receive the same service.

restricts output), the gains from international trade (which makes more goods available), the effects of agricultural price supports (which may restrict output and raise prices), and the social benefits of innovation (which leads to lower costs and development of new goods).

Several studies on innovation using the consumer surplus approach have been published. Peterson 1/ evaluated the effects of poultry research. Griliches 2/ estimated the rate of return on investment in hybrid corn research. Schmitz and Seckler 3/ used this approach to estimate the rate of return on investment in a mechanical tomato harvester.

"Producer's surplus" is an analogous concept. It is used to measure producer's benefits from reduced production costs. A cost-reducing innovation usually leads to a reduced consumer price, but depending on market characteristics, some benefits remain with producers in the form of higher profits.

One of the main theoretical justifications for Government research and development is related to these two surpluses. Profit-maximizing firms, some argue, base their R&D investment decisions on profitability, ignoring consumer benefits (consumer surplus). From society's point of view, this may lead to under-investment in research and development. From this follows the familiar assertion that the social rate of return from R&D investment significantly exceeds the private rate of return.

Edwin Mansfield's recently completed study of innovations' rate of return exemplifies this methodology's current applied

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1/W. L. Peterson, "Return to Poultry Research in the United States," Journal of Farm Economics, vol. 49, Aug. 1967.

2/Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, vol. 66, Oct. 1958.

3/A. Schmitz and D. Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," American Journal of Agricultural Economics, vol. 52, Nov. 1970.

state of the art. 1/ Seventeen average or routine innovations, such as a new type of household cleansing device, by private firms were intensively analyzed, and the average private and social rates of return were estimated. But benefits and costs were compared for the total innovation effort. Even in the case of routine innovations, R&D spending is followed by advertising and distribution and may be preceded by market research.

It is unlikely that R&D spending alone would achieve the innovation results, since research and development is is directed at overcoming only technological or scientific barriers (if there are any). At a minimum, commercial establishments must be induced to sell the product and end users must be made aware of its existence and be induced to buy it. In these cases, when a total input-total output approach was adopted, what portion of the innovation output do we attribute to R&D spending? This question is not addressed in Mansfield's study.

Another problem is cost or price reductions. Bela Gold, in a critical evaluation of economic analysis, noted that in addition to focusing on cost and price reductions or profit increases, we might also focus on

> "* * * mitigating expected increases in input factor prices or decreases in availability of needed raw materials; responding to buyer demands for higher-quality products; and acceding to governmental pressures relating to labor or community health, safety, and pollution standards." 2/

THE AGGREGATE ECONOMIC APPROACH

The second major approach to measuring the outputs of R&D spending uses highly aggregated economic data. The idea is to explain how research and development contributes to total productivity growth of the National economy or specific

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1/Edwin Mansfield, et. al., "Social and Private Rates of Return From Industrial Innovations," Quarterly Journal of Economics, May 1977.

2/Bela Gold, "Research, Technological Change, and Economic Analysis: A Critical Evaluation of Prevailing Approaches," Quarterly Review of Economics and Business, Jan. 1977, p. 20.

industries over some period. This approach requires careful statistical sifting of productivity data to determine the individual contribution of various economic factors to changes in aggregate productivity. There are numerous pitfalls--errors in data, errors in specifying the production relationships, and technical statistical problems. Precise measurements are illusive with this approach.

Even after the components of productivity change are sorted out, to accurately measure the R&D contribution is probably impossible. There is unquestionably a contribution and possibly a large one, but pinning it down is beyond the current state of the art.

Even measuring research and development for purposes of aggregate analysis is exceedingly difficult. The R&D inputs may not be sufficiently similar to warrant grouping them all into the same category. 1/ Certainly research and development performed by industry ($26.6 billion in 1976), which includes research and development funded by industry ($16.3 billion) as well as research and development performed in industry but funded by the Government ($10.3 billion in 1976), is a diverse category. 2/ The conventional classifications of basic research, applied research, and development each encompass many activities. New products, product improvements, or even process improvements may be the goal of R&D.

> "R&D may also include undertakings to facilitate shifts to lower quality or cheaper material inputs, to mechanize labor tasks, to improve machine efficiency, to meet health, safety, noise and pollution requirements * * *." 3/

Moreover, there is widespread concern that industrial research has recently become more oriented toward trying to satisfy governmental regulatory requirements; thus, the purpose of the R&D dollar may be changing over time and across industries.

1/Gold, op. cit., pp. 12-13.

2/George E. Manners, Jr. and Howard K. Nason, "The Decline in Industrial Research - Causes and Cures," Research Management, Sept. 1978.

3/Gold, op. cit., p. 17.

Studies that take a highly product- or process-specific approach to output measurement by using the concepts of consumer and producer surplus are extremely useful for valuing the total output of an innovation effort. A framework for valuing Federal R&D output must be highly program or subprogram specific; estimated impacts of the total R&D budget are too speculative and too aggregated to give much policy guidance. The problem with the consumer surplus approach as it affects measurement of Federal R&D output is that a R&D marginal product measure is preferable. Since most Federal commercially-directed innovation programs are more complex than average or routine innovations, some means of evaluating interactions between program inputs should also be found.

Production function theory may be helpful in this regard. As indicated above, estimating R&D output at highly aggregated levels should consider the impacts of capital and labor inputs on output. (Rather than employing the aggregated production function methodology described above, it may be useful for decisionmakers to think of a Federal innovation production function in which (1) output is measured as the preultimate output of an innovation effort; and (2) inputs are all incentives, including R&D, used to bring about the innovation's result.) This, of course, is far easier said than done. Nevertheless, it is useful to think in terms of a framework that (1) captures at least the essential elements of the innovation process as described in chapter 2; (2) determines the marginal product of R&D spending in the context of an innovation production function; and (3) values the output of Federal R&D by empirically estimating social and private returns using the concepts of producer and consumer surplus.

It is useful to summarize at this point. The Federal innovation process is complex and involves long lead times and much uncertainty. The conceptual framework for appraising Federal commercially directed R&D requires an appreciation and understanding of the innovation process and draws heavily on the professional literature which deals with the working of this process in our economy.

The contribution of Federal R&D to this process needs to be evaluated in the context of all other factors affecting commercial acceptance of an innovation. R&D is useful for overcoming scientific and some technical barriers. But there are other barriers that impede delivery of an R&D result into widespread commercial use. To achieve market acceptance of an R&D result, all institutions involved in the marketing, manufacturing, distribution and end use of the technology must be induced to accept its usefulness. A mix of program options including financial assistance, procurement, tax credits, price supports, etc., may be necessary to overcome these barriers since they cannot be overcome by R&D spending alone. Policy inputs and R&D spending all contribute to the realization of a commercial result.

A valid but complex approach to measuring the output of Federal commercially directed R&D spending should model impediments to commercial success and the policy inputs and R&D spending necessary to overcome them. The market price of the products resulting from the R&D and the value of the products to consumers or ultimate end users should then be estimated using economic surplus concepts. Then, one of two measurement approaches from production function theory could be used for measuring innovation program output or R&D spending output.

--A total input-total output approach where the measured output is compared with total program costs which consist of R&D cost and other program input costs.

--An incremental product approach where the marginal output of R&D spending given levels of all other program inputs is compared with R&D costs.

The second of these approaches is the most difficult but also the most useful. First, it would enable decisionmakers to assess the incremental outputs of research and development and each of the other policy inputs to decide whether too much or too little is spent on R&D vis a vis other inputs. Second, assuming a budget constraint, R&D spending should be allocated to those projects in which the marginal output of R&D spending is highest.

CHAPTER 5

DOE'S SOLAR PHOTOVOLTAICS PROGRAM

This chapter discusses the previously developed concepts in the context of a specific--though broad--federally funded commercially directed R&D program. solar photovoltaics.

The sun's energy can provide electricity for uses ranging from onsite residential applications to large-scale central station powerplants. One means of accomplishing this is through the photovoltaic effect. Sunlight striking a semiconductor device composed of two layers of different types of silicon material produces a direct electrical current. The direct current must be converted into alternating current by an inverter. Since there can be considerable discrepancies between the supply of sunlight striking photovoltaic arrays and the demand for the electricity produced, a storage medium is necessary. In residential applications, storage might be accomplished by participating in a power grid in which excess solar-generated electricity is sold to a central power system and then repurchased when needed.

Photovoltaic devices are now technologically feasible. They have been used extensively to supply power for manned and unmanned space vehicles. Other applications have been made in remote locations where the costs of supplying central station power are prohibitive. Right now photovoltaic devices are usually too expensive for residential, commercial, or industrial process heat markets. The photovoltaics R&D program is designed to reduce costs significantly. Basic research and system development phases for some technologies have been completed, and other photovoltaic technologies are in a manufacturing cost reduction stage.

In 1978 the cost of producing arrays (as opposed to total system costs) was $11 a peak watt. DOE has established intermediate and long-run cost reduction goals of $2 in 1982, $0.50 in 1986, and $0.10-$0.30 a peak watt by 1990. 1/ These costs are only one part of installed system costs. Costs of storage technologies are also very high--$80 to $100 a kilowatt-hour. Inverters are also expensive, especially for small site use; they cost as much as $500 for 2-kilowatt capacity. Large inverters cost somewhat less per kilowatt-hour; increasing capacity from 1 kilowatt to 100 kilowatts reduces the cost from $500 to $50 per kilowatt-hour. These nonarray costs can

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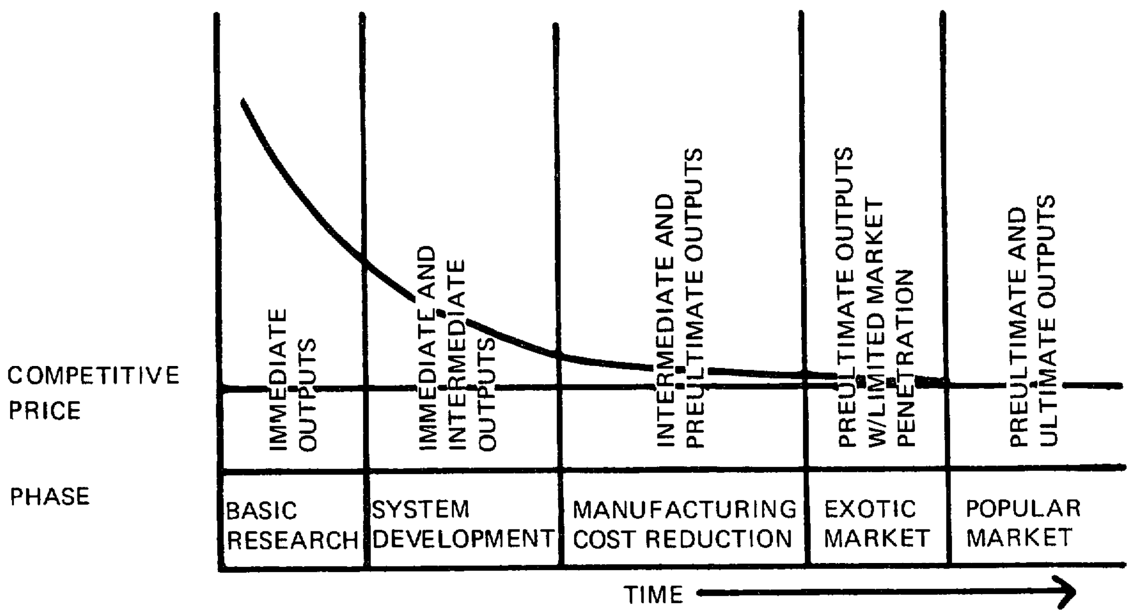
1/Figures are in 1975 dollars. In 1980 they will change.

more than double installed systems costs over array costs. 1/

Rubenstein classifies such cost reductions as intermediate outputs. They are not preultimate outputs because no basis exists for assuming that total system prices based on such costs would be economically competitive and therefore achieve market acceptance. The relationship of cost reductions to the innovation process is displayed in figure 2.

Figure 2

Cost Reductions During the Innovation Process



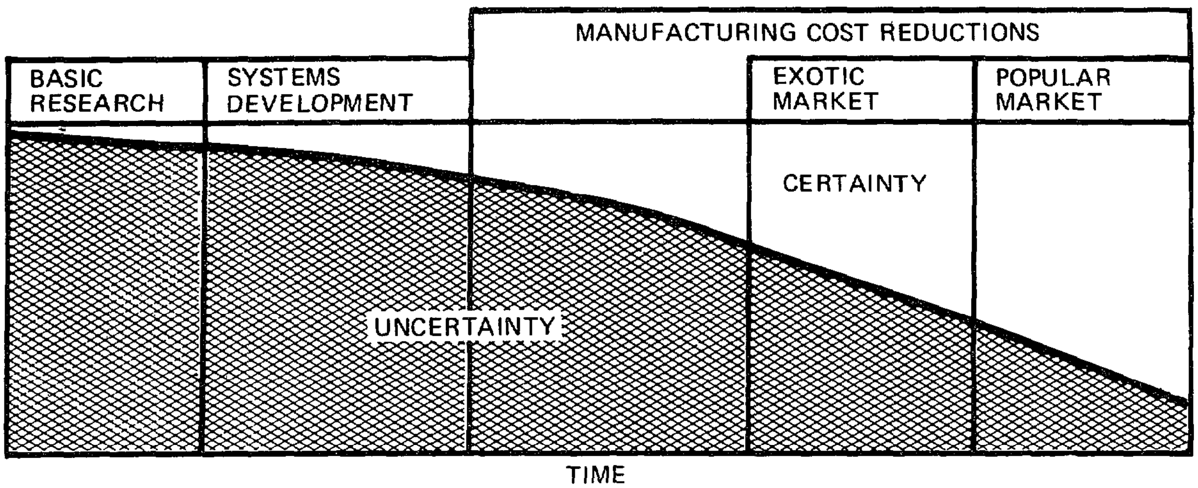
The effect of R&D can be discussed in terms of reduced cost level eventually achieved or the rate at which cost is reduced.

1/"Application of Solar Technology to Today's Energy Needs," vol. 1, Office of Technology Assessment, June 1978, and "Preliminary Report: Photovoltaics Incentives Options," U.S. Department of Energy, Aug. 1978.

Along the output continuum, uncertainty exists in the basic research and systems development phases. Having successfully passed through these stages (or, at least, having some outputs that have successfully gone to the point of pilot manufacture), the uncertainty associated with achieving subsequent goals is reduced and to some extent the uncertainty of achieving preultimate output goals is increased. Figure 3 illustrates this reduction in uncertainty. 1/

Figure 3

Uncertainty Reductions During the Innovation Process



As indicated in the diagram, manufacturing cost reductions occur through innovation and continue well into the diffusion process.

Meeting cost reduction goals does not constitute evidence that something of value will be produced. Information on whether the 1990 goal of $0.10 to 0.30 a peak watt array cost will be economical is not available. Suppose that the cost reduction goals are met but no market penetration occurs

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1/Derived from "Weapons System Duplication: Problems and Reforms," The GAO Review, U.S. General Accounting Office, Summer 1977.

because the price of competing fuels is lower. If this happens, no reasonable value can be assigned to the progress of the innovation except that then one might have a better idea of how to achieve further cost reductions. Alternatively, if solar photovoltaics were economically competitive at $10 a peak watt 20 years from now, achieving the goals would be very valuable. This is why cost reduction goals and achieving them are not very meaningful when viewed in isolation. They assume importance only when viewed favorably relative to expected prices of competing fuels.

Nevertheless, for monitoring or tracking purposes, one reasonable measure of intermediate outputs is the extent to which actual cost reductions conform to program goals. If nothing else affected the popular market's acceptance of photovoltaic technology, analyzing the reduced uncertainty associated with achieving cost goals would be very helpful in realistically appraising the probability of achieving end-use goals and their value.

Thus, there are two aspects to the evaluation of intermediate outputs in the photovoltaics program. On the one hand, measuring the relationship between cost reduction goals and the realization of those goals can provide a measure of intermediate output. On the other hand, the relationship of program goals to the changing prices of energy alternatives must be monitored in light of measured current progress.

Research and development and demonstration will rarely accomplish both cost reduction and ultimate output goals. The technology must be delivered into widespread commercial use to meet the program's economic goals. This requires a technology delivery system with the characteristics described by Ezra.

BARRIERS IN THE INNOVATION PROCESS 1/

Barriers are present throughout this process. They may be discrete, like technical barriers, or they may be

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1/This discussion of barriers and the discussion of incentives draws heavily on "Preliminary Report: Photovoltaic Incentives Options," U.S. Department of Energy, Aug. 1978; "The Magnitude of the Federal Solar Energy Program and the Effects of Different Levels of Funding" Report of the Comptroller General of the United States, U.S. General Accounting Office, Feb. 2, 1978; and Ezra, op. cit.

continuous, such as financing the institutions involved in the process.

Current low market demand for photovoltaic arrays is due to lack of information, uncertainties regarding costs, problems of retrofit as opposed to new installations, high production costs, costs of alternatives and reliability. Supply and demand constraints are interdependent. The choice of the most cost effective, reliable technology might be made in the absence of market demand considerations, but the optimal size for an array-manufacturing plant cannot. Producing firms must have good estimates of potential market size at varying prices to determine plant size. The simultaneity of supply and demand impediments and their cost implications for installed systems are a very significant barrier to innovation output from the program.

Unless storage technologies are improved, photovoltaic applications will require a backup utility connection. Because of this, the ownership of a photovoltaic system must be determined to the satisfaction of interested parties, rate structures must be revised to prevent discrimination against photovoltaic systems, and a procedure for selling excess photovoltaic energy to utilities must be developed.

The near-term supply of silicon may be an important impediment. Presently, the supply is adequate for both the semiconductor and the photovoltaics industries. However, combined projected growth in both industries will outpace supply by 1982. Since the cost of silicon used by the semiconductor industry is low in relation to its product's total cost, it will have a bidding advantage over the photovoltaic industry. Therefore, the supply of silicon must increase. Dow Corning estimates that to bring a new silicon production plant on line would take 3 years; and if a plant produces silicon for $60 a kilogram capitalization costs would be $90 a kilogram. Thus a plant producing 100 metric tons a year would cost $9 million. 1/ Required capital investment in silicon capacity will be $1.3 billion by the year 2000.

If solar cell production goals are to be met, total investment in all aspects of photovoltaics system production capacity of $29 billion to $42 billion must occur between now and the year 2000. Producers' willingness to invest

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1/"Preliminary Report: Photovoltaics Incentives Options," U.S. Department of Energy, Aug. 1978.

and lenders' willingness to supply between $1.5 billion and $2 billion a year over this period are questionable, unless there are strong grounds for expecting increasing demand for photovoltaic systems.

Current industry concerns about the photovoltaics program are summarized in a DOE study. 1/ In general, concerns center on DOE's desire to achieve near-term goals, which may jeopardize long-term goals; and on uncertainties about the market, materials costs and availability, supporting technologies, the Government's involvement, and the technology. Specifically:

"(1) Investment in production equipment and facilities that are likely to experience rapid economic and/or technical obsolescence.

"(2) Investment in production equipment for automation and/or expansion of production capacity without assurance of long-term sustaining markets.

"(3) Investment in the wrong technology(ies) (e.g., flat plat vs. concentrators; silicon single crystal vs. thin film, ribbon or sheet; silicon vs. GaAs or CdS), in terms of what technologies will best push cost reductions and what technologies will best fit the long-term markets, and in terms of first, second and third generation technologies.

"(4) Capital investments in response to government program with little assurance that program will not change in the near-term and cease to absorb investment risks.

"(5) Choice of the wrong approach to markets, in terms of return on investment and in terms of ability to obtain reasonable market share in long-term markets, e.g., choice of component vs. system vs. end-product sales.

"(6) Investment in production expansion with possibility that price goals may not be achieved and expanded markets may not materialize.

1/U.S. Department of Energy, op. cit., pp. VI-19 to VI-30.

"(7) Even if price goals are achieved, realized sales volume could fall far short of DOE growth objectives.

"(8) The risk that the industry may collapse when government backs out, if the gap between the subsidized and free markets is too great." 1/

A final impediment worth mentioning is the unresolved legal issue of "sun rights." Installing photovoltaic arrays is less attractive if owners are uncertain that the collector will be shaded by some new structure. Local building codes will have to deal with this issue before arrays are widely used.

INCENTIVES

An infrastructure for manufacturing, delivering, using, and servicing solar cells has not developed. Introducing photovoltaic systems into a Federal or civilian market will require a number of interactive Government incentives to affect the infrastructure. The available Government incentives are

--Taxes;

--Government procurement;

--Grants,

--Ownership, demonstration;

--Cost sharing/leasing;

--Financial assistance;

--Regulation;

--Testing, certification, approval;

--Training;

--Information dissemination; and

--Advocacy.

1/U.S. Department of Energy, op. cit., pp. VI-25 to VI-26.

All these may be used to varying degrees. Some cost more than others, and depending on circumstances, some are more effective than others. A full discussion of the merits and drawbacks of each incentive is beyond this paper's scope.

Tax incentives--Tax incentives are often used to influence economic behavior, and they can be used to accelerate commercialization of solar cells. Even when life cycle costs favor solar energy systems, the initial cost of solar equipment remains a major deterrent to use. Tax benefits granted to those who purchase or manufacture solar equipment may offset this deterrent.

Government purchases and grants--Massive Federal purchases for the near term have been suggested to drive down production costs. Once prices are reduced, normal market forces and other less expensive incentives can presumably sustain market growth. This incentive works if the product requires little adaptation for the private marketplace and if the product is demanded by consumers.

Making the Federal Government the dominant purchaser concerns some because the Government may "overspecify" the product requirements and freeze technology advances, thereby inhibiting price reductions and product improvements. To avoid this problem, the Government can award funds to grantees who will then purchase solar devices commercially.

Government ownership, leasing, demonstration--Mass production of solar cells requires new capital intensive manufacturing equipment. Rather than creating a market and assuming that capital will be forthcoming, the Government can build production facilities and permit private concerns to operate them. A variation of this is partial Government ownership of the plant or the plant's manufacturing equipment. This type of incentive helps overcome the perceived risks, which deter private sector investment in acquiring costly, long-term specialized assets.

Demonstration projects often stimulate an innovation's commercialization. They provide authentic data on production costs, performance, reliability, and public acceptance. If the company involved in the project can continue commercial sales after completing the demonstration project, the innovation stands a better chance of becoming an economic benefit benefit.

Cost sharing--The Government regards cost sharing as an indication of industrial interest in a Federal invention.

It is believed to raise the level of technical and economic risk that a firm will accept. The willingness to share costs may also indicate the institution's true interest in using the innovation.

Credit assistance--Loan guarantees can encourage investment in solar technologies by (1) raising the level of risk that a lending institution will accept and (2) increasing the cash flow to the loan guarantee beneficiary. In this situation, the Government places its credit behind the investment by underwriting a loan to private firms to build special equipment or manufacturing plants.

Government regulation--The Government, through its regulatory powers, can encourage the use of solar energy. For example, the relative costs of solar energy can be decreased by increasing the cost of conventional fuels and by increasing taxes on gasoline or fuel oil. Solar energy use can also be encouraged by limiting available conventional fuels through import quotas or by curtailing production orders. Government testing and specifications for new products may also serve as market incentives. Since many believe a few bad experiences by consumers can damage the future of the photovoltaic industry, Government performance specifications can inspire public acceptance of new products. Specifications can also help State and local governments to write ordinances, codes, and regulations governing solar cell use.

Grants--Grants to cities or States for demonstration and other projects provide incentives for using R&D results. Grants to private companies are also possible, though these are usually made in connection with cost-sharing arrangements. Grants can overcome problems that direct Government procurement may cause--overspecification and application--since grantees can adopt solar energy projects that meet their needs more closely. Grants to nonprofit institutions enable them to continue current and future research and development.

Training--Training people is an incentive in the development of an infrastructure. Probably no one group of tradesmen has all the requisite skills needed to install a complete photovoltaic system. The Government can train people in the necessary skills

Information dissemination--Information dissemination is a major step in getting R&D results to potential innovation users. Generally, however, the distributed information is insufficient to induce institutions to invest in an innovation because many questions remain unanswered. Thus, the technical services of the R&D performer are generally required in addition to the innovation information.

Patents--Almost all federally sponsored R&D is currently in the public domain (excluding defense R&D). Basically, this means a company who wishes to use Federal R&D results has no patent protection. Companies are averse to using Government innovations unless all potential production problems have been solved. Nonexclusive patents are thus weak incentives. Exclusive patents when available are little better because the Government has failed in the past to enforce such rights. 1/

Advocacy--Government advocacy of photovoltaics increases the incentive for using R&D results because the private sector believes Government support will continue throughout the lengthy innovation and commercialization period.

THE TECHNOLOGY DELIVERY SYSTEM

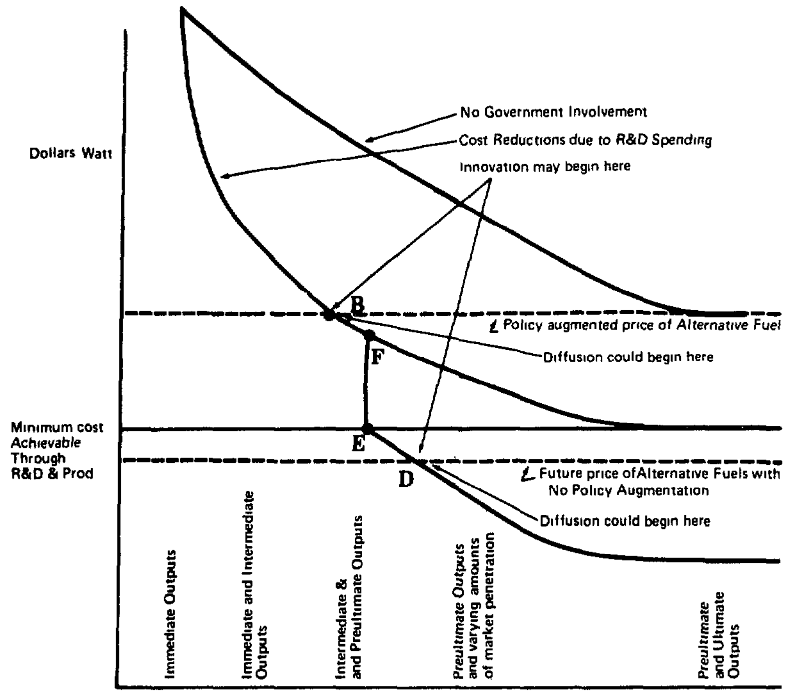
Figure 4, an expanded version of figure 2, shows a cost profile of photovoltaic installed system costs, a range of uncertainty associated with those costs, a list of the institutions involved in the process, the incentives that may be required to promote participation of such institutions in innovation and diffusion, and a cost curve of a hypothetical situation in which there is no Federal involvement. Whatever program preultimate outputs flow, they arise because the ultimate results are achieved more quickly than with no Federal involvement.

The stages of the innovation process running from basic research through outputs diffusion are arrayed along the bottom of the figure, and Rubenstein's output classification defines the expected output of each stage. Cost reductions are shown through all stages, but the process contains a range of uncertainty. Without Federal support, we presume cost reductions to be slower. Though process uncertainty is reduced, successes and failures may be monitored (failures are outputs too, since they also reduce the range of uncertainty) and knowledge is generated regarding the achievement of cost reduction goals.

1/The Department of Energy does grant waivers so that commercial establishments maintain rights.

Figure 4

Photovoltaics Innovation Process (Note a)



Basic Research (Systems Concepts)	System Development (Preliminary Development & Eng)	Manufacturing Cost (Final Development & Limited Prod Full Prod)	Time ⟶

INSTITUTIONS

Private & Govt Res Labs	R&D Performers Equip Manufacturers Lending Institutions Local Govt Architects	R&D Performers Equip Mfgs Lenders Loc Govt Architects Home Bldrs Labor Unions Builders in General	Home Builders Lending Institutions Labor Unions Home Owners Commercial and Industrial Users

INCENTIVES

R&D Funding (Multi technology)	Information Dissemination Licensing Demonstration Testing Federal Cost Sharing No Cost Leasing of Demo Plants for Manufacture Limited Fed Procurment Limited Loan Guarantees Performance Specifications Market Research	Information Dissemination Licensing Potentially More Fed Procurment Cost Sharing Loan Guar More R&D Fed Specs	More Information Dissemination Continued Demos Loan Guarantees Construction Grants Training Grants

a/ Uncertainty is present throughout the entire process

The institutions involved may include Government and private research laboratories, universities, and the like, which produce "laboratory" as opposed to "factory" alternative configurations of photovoltaics. Basic research may yield many promising alternative configurations. Depending on the scientific barriers overcome, some alternatives may go into the system development stage, while basic research and development continues on others.

The system development stage includes R&D performers, equipment manufacturers, lending institutions, and others. Incentives for obtaining their involvement may include such complementary activities as information transfer and dissemination, licensing, demonstration grants, testing, Federal cost sharing, no-cost leasing of demonstration plants, procurement, loan guarantees, performance specifications, and market research. All these, along with R&D spending, may be shown as movement down the cost curve, and hence, reduces uncertainty about the probability of achieving output goals. During this stage basic research results are transferred to private performers so that they may acquire knowledge of the technology. Knowledge is not costless and is not strictly a result of R&D spending. Reduced costs and uncertainties may be compared with program costs and goals at this stage.

In figure 4, two principal types of cost reduction are represented. The first, "cost reduction due to R&D spending," plots cost reductions achieved through R&D spending, procurecurement, demonstration projects, and so forth. The basic idea is that cost reductions may occur by selecting the best photovoltaic technological alternatives, determining the most cost effective mix of factor inputs in producing outputs, and determining the optimal scale of production. In the hypothetical example, the minimum cost achievable at optimal scale is not economically competitive with that of other fuel sources. Given program goals and the inability to produce and sell solar arrays at competitive prices, other Federal incentives, such as those discussed previously, are needed to further reduce the cost to users. This is shown in the diagram as a downward shift in the cost reduction curve from point F to point E. The combination of policies designed to reduce costs also affects supply and demand. Curve ED implies a shift of the supply curve of uneconomic photovoltaic arrays into the competitive price range.

An alternative policy for stimulating array demand is to raise competing fuel prices. This is possible in a number of ways. It is important to distinguish between policies that result in fuel prices which are a true reflection of fuel scarcity, and those that artificially inflate alternative fuel prices. Many policy mixes may be used to affect favorably the comparison of the cost of photovoltaic arrays with competing fuel prices. These policies have varying costs and, assuming array acceptance, varying benefits. Both will depend on the price differentials between photovoltaics and competing fuels and on the mechanisms (if any) used to raise fuel prices.

"Diffusion" begins when photovoltaics become competitive. The total innovation benefits up to that point may be found by comparing output from the Federal program with the output that would have occurred had there been no Federal sponsorship. The basic benefit is that alternative fuels are displaced sooner than with no Federal program. The value of this benefit is the amount of displacement relative to no policy times the price difference between photovoltaic and competing fuels. In figure 4, comparison may be made on a unit cost basis, but since no quantity dimension exists, benefits cannot be calculated in dollars.

Suppose that no Federal policies were used to affect competing fuel prices. Assume the mix of policies used was designed to reduce the effective cost of photovoltaics below competing fuel prices. Then innovation would occur at point D and diffusion would continue until total demand was satisfied.

It is interesting to speculate on whether in this situation foreign oil prices would decline to remain competitive with those of photovoltaics. This is not unreasonable to expect, particularly in view of the huge profit margins currently obtained on oil produced by the Organization of Petroleum Exporting Countries (OPEC). Even if photovoltaics were not widely adopted because of lower oil prices, the benefit calculation would be the same because without the program, oil prices would not have fallen. 1/

With a policy designed to raise competing fuel prices, diffusion could begin at point B. Clearly other things can affect the comparative attractiveness of photovoltaic technologies. Aside from spectacular scientific or technological breakthroughs, research and development is not absolutely necessary to achieve program goals. But achieving market acceptance through a policy of price increases on competing

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1/It is doubtful that photovoltaics will ever be in strong competition with oil as an energy source. But all the newly developed energy sources might very well help limit OPEC price increases.

fuels can be very expensive if price levels do not reflect the true scarcity of competing fuels. If, for example, the increased competing fuel prices were totally artificial, that is, induced by policy, then a net cost--not a benefit--would result. If, on the other hand, a higher future price of competing fuels reflected true scarcity, then program benefits could be large.

Whatever the benefits of the program are, they must be weighed against their costs to arrive at cost benefit ratios or rates of return on investment. Costs and benefits should be measured using the concepts of consumer and producer surplus described earlier. In figure 4, the reduced price of energy resources times quantity demanded with a Federal photovoltaics program would be compared with competing fuel and/or photovoltaic array prices under a policy of doing nothing. Such benefits should then be compared with total program costs for purposes of making decisions about resource allocations.

As a summary of these considerations, chapter 6 presents some basic questions that should be asked regarding any Federal commercially directed R&D program.

CHAPTER 6

QUESTIONS WHICH SHOULD BE ASKED REGARDING FEDERAL COMMERCIALLY DIRECTED R&D PROGRAMS

In practice, it is very difficult to obtain the data needed to apply the approach to assessing R&D output in a literal way. In the case of photovoltaics, the price of future output resulting from today's R&D spending is very difficult to estimate with any degree of certainty. Furthermore in our case study, relative photovoltaic prices are more important than absolute price levels when estimating chances of program success. These two considerations are likely to be characteristic of many Federal commercially directed R&D programs. Also, as noted, determining the contribution of R&D spending is difficult because of long lead times and because R&D is but one of many program inputs. Limitations in data availability, uncertainty, and other factors suggest that the usefulness of our approach lies primarily in its ability to provide guidance in asking the right questions about R&D projects on a systematic basis.

The following questions suggest themselves.

1. What economic benefits will this program produce (e.g., units produced, reduced prices, resource savings, quality improvements)? What will total program costs be? When will benefits begin? Are goals clearly defined? Can progress toward them be measured?

2. What noneconomic benefits will the program produce (e.g., environmental impacts)? What is their estimated value?

3. Is a Federal role in producing the purported benefits necessary? Why is any R&D spending, or a proposed level of R&D spending, necessary when there may be alternative incentives, such as tax expenditures, regulation, and financial assistance, which may achieve the same result in a more cost effective manner?

4. What immediate results are expected from the expenditure of research and development funds (e.g., laboratory results, technical papers)? What is the significance of those results,

particularly as they affect realization of expected economic and noneconomic benefits? What sequential steps are involved in each stage of the innovation process and who will be involved in each stage?

5. If immediate results are potentially economic, by what mechanism(s) will others, such as equipment manufacturers and R&D performers be induced to adopt such results (technology transfer, procurement, regulation-deregulation, etc.)?

6. How will these mechanisms interact in helping industry adopt the immediate results of Federal R&D spending? For example, can technology transfer alone achieve the application objective? If not, how do other mechanisms help produce the transfer?

7. What are the intermediate output goals (e.g., cost reduction) of the program? If a goal is to be in phase A by year X and phase B by year Y, how do the mechanisms and R&D efforts contribute to achieving such goals?

8. What are the relationships between program intermediate results and expected ultimate economic and noneconomic benefits? If we reach phase A by year X and phase B by year Y, what assurance is there that such results will inevitably lead to the economic and noneconomic benefits expected?

9. What additional policy mechanisms are required to go from phases A or B to realization of economic and noneconomic benefits? In other words, given that equipment producers, R&D performers, regulatory bodies, lending institutions, etc. have accepted the technology's merits, what additional inducements (if any) will be required to achieve commercial market acceptance? (Financial assistance? Why? Tax credits? Why? Regulations, standards, certification? Why?)

10. How will these mechanisms work standing alone and interacting with other incentives? For example, tax credits alone may do very little to stimulate solar technology use even though the technology is competitive with central power plants on a life cycle cost basis after the tax credit. Financing may not be available due to reluctance to lend

funds for the technology. Thus, other forms of financial assistance might be required to bring the technology into widespread use.

11. Given the program's expected economic benefits, the incentives used, and the interactions between incentives, what is the marginal contribution to gross economic benefits of R&D spending, at given levels of input of the other incentives?

The last question is extraordinarily difficult to answer. One approach is to assume no R&D spending, and ask what costs would be incurred if other incentives were increased to produce the results obtained when R&D spending is part of the program. If these costs exceed previous costs, then the net benefits of R&D spending are positive. However, this does not mean that the overall program produces a net economic benefit. Cost may exceed benefits with or without research and development input. On the other hand, if the R&D results can be produced more cheaply by other means, then the research and development is obviously not cost effective.

Research and development should be expected to accomplish two things. First, it should demonstrate the technical feasibility of a particular product or process. Second, it should create improvements that will ultimately produce either a higher quality product or process, or a lower priced product or process that has some end use. Presumably cost or price reduction or quality improvements that R&D spending can produce for an innovation are limited. At this level, the product or process may or may not be commercially acceptable. If it is not (and this is generally the case), other costs will be incurred in bringing the product or process to market.

Federal R&D programs have the peculiarity that once scientific or technical feasibility has been proven, many alternatives may be used to induce market acceptance. Research and development is only one means of reducing costs to consumers for end uses of a particular technology. Other policies, such as tax credits, financial backing, outright grants, etc., may produce effective cost reductions very similar to those achievable with research and development. By creating market demand for a product, additional cost reductions due to economies of scale in production may develop.

It is important to recognize that R&D spending benefits are limited and that other means may achieve essentially the same result. The question then becomes whether research and development is more cost effective in contributing to economic benefits than the alternatives. As mentioned, one way of determining this is to compare the expected costs of the program with and without an R&D component. If the same result can be produced at a lower cost with an R&D component, then the cost reduction achieved may be compared directly with R&D costs. Alternatively, if greater benefits result because of an R&D program input than result with no R&D and total program costs remain constant, then the additional output may be attributed to R&D at given levels of other incentives.

We do not mean to imply that all the effects we describe can be measured precisely--they cannot. But we do believe that if the above questions are answered carefully on the basis of the best information and estimates available, the information gleaned from the answers will substantially improve the ability of policymakers, agency officials, and the Congress to make informed judgments about Federal expenditures for commercially directed R&D programs.

AGENCY COMMENTS

We obtained informal comments from the National Science Foundation, Department of Energy, American Association for the Advancement of Science, and the Congressional Research Service. Those commenting thought that the framework presented here represented very good progress. Some questioned, however, the practical applicability of the framework in view of the lack of data, uncertainty, and multiple objectives involved in Federal R&D activities. As the preceding discussion makes clear, GAO recognized that the framework which we discuss cannot be implemented on a literal basis and that allocation of resources in the commercially directed R&D area necessarily involves judgments about many complex factors. However, we also believe systematic effort to gather the type of information suggested here would help executive branch officials and the Congress to make their judgments on the basis of information of better quality than now generally is available.

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