GOVERNMENT SUPPORT FOR THE COMMERCIALIZATION OF NEW ENERGY TECHNOLOGIES

An Analysis and Exploration of the Issues

MIT-EL 76-009

November 1976

Energy Laboratory Report
MIT-EL 76-009

Energy Laboratory Report
MIT-EL 76-009.
Standard Distribution

GOVERNMENT SUPPORT FOR THE COMMERCIALIZATION OF NEW ENERGY TECHNOLOGIES

An Analysis and Exploration of the Issues

by

Policy Study Group
Energy Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Date Published--November, 1976

PREPARED FOR THE UNITED STATES

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Under Contract No. E(49-18) 2295
Task Order 6

ABSTRACT

This report examines the issues associated with government programs proposed for the "commercialization" of new energy technologies; these programs are intended to hasten the pace at which target technologies are adopted by the private sector. The "commercial demonstration" is the principal tool used in these programs. Most previous government interventions in support of technological change have focussed on R&D and left to the private sector the decision as to adoption for commercial utilization; thus there is relatively little in the way of analysis or experience which bears direct application.

The analysis is divided into four sections. First, the role of R,D&D within the structure of the national energy goals and policies is examined. The issue of "prices versus gaps" is described as a crucial difference of viewpoint concerning the role of the government in the future of the energy system. Second, the process of technological change as it occurs with respect to energy technologies is then examined for possible sources of misalignment of social and private incentives. The process is described as a series of investments. Third, correction of these sources of misalignment then becomes the goal of commercial demonstration programs as this goal and the means for attaining it are explored. Government-supported commercialization may be viewed as a subsidy to the introduction stage of the process; the circumstances under which such subsidies are likely to affect the success of the subsequent diffusion stage are addressed. The discussion then turns to the political, legal, and institutional problems. Finally, methods for the evaluation and planning of commercial demonstration programs are analyzed. The critical areas of ignorance are highlighted and comprise a research agenda for improved analytical techniques to support decisions in this area.

PREFACE AND ACKNOWLEDGMENTS

On October 15, 1975, the Administrator of the U.S. Energy Research and Development Administration appointed a Task Force on Demonstration Projects as a Commercialization Incentive. The Chairman of the Task Force is Dr. Robert A. Charpie, President of the Cabot Corporation, and the members were chosen to represent the principal groups involved in commercialization decisions in the energy field. The purpose of the Task Force is:

> ...to examine the demonstration project as a commercialization tool in both its technical and nontechnical aspects in order to recommend to ERDA new methods of designing technical demonstrations which will make these demonstrations responsive to the nontechnical uncertainties involved in commercialization decisions.

This Issue Paper has been prepared in support of the work of that Task Force.

As part of the work of this project, five studies were performed on specific technologies which either are, or have been, the subjects of government-supported commercialization programs. They are appendices to this report and are or will be available separately from the M.I.T. Energy Laboratory. They are listed in the Table of Contents.

We would like to specifically acknowledge the monitors of this effort at ERDA, Mssrs. Thomas A. Calhoun and A. Denny Ellerman. Our interaction with Denny Ellerman in particular was fruitful and stimulating, and he contributed substantially and substantively to the conceptualization involved in this work. We also received provocative and useful criticism on drafts of this paper from a number of individuals in academia, industry, and government. To them we express our gratitude.

PARTICIPANTS

The following members of the Policy Study Group of the M.I.T. Energy Laboratory participated in the preparation of this report:

Henry D. Jacoby, Professor of Management (Co-principal Author)

Lawrence H. Linden, Research Staff, Energy Laboratory; Lecturer in Mechanical Engineering and Management (Co-principal Author)

M.A. Adelman, Professor of Economics

Ben C. Ball, Visiting Senior Lecturer, Sloan School of Management

Ted R.I. Greenwood, Assistant Professor, Political Science

Ogden H. Hammond III, Research Staff, Energy Laboratory; Lecturer in Chemical Engineering

Stewart C. Myers, Professor of Finance, Sloan School of Management

J. Daniel Nyhart, Associate Professor of Management and Ocean Engineering

David O. Wood, Associate Director, Energy Laboratory

Martin B. Zimmerman, Research Staff, Energy Laboratory; Lecturer in Management

They were assisted by the following:

Sudipto Bhattacharya, Research Assistant, Management

Beverly J. Bugos, Research Assistant, Political Science

James W. Meyer, Research Staff, Energy Laboratory

Paul R. Samuelson, Research Assistant, Management

Bruce E. Stangle, Research Assistant, Management

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

SUMMARY

The United States government has set out to "commercialize" a number of new energy technologies. This is a relatively new role for federal agencies. Except in areas (such as defense) where the sponsoring agency was simultaneously the customer for the results, public expenditure on technology has generally been confined to research and development. The pace of the process whereby new technologies were put to commercial use, and the decisions about the investments that make up that process, were left to the private sector.

The energy problem is leading us to depart from this norm. Through the Energy Research and Development Administration the government is investing substantially in energy technology, and there is natural pressure--from the Congress, the agency itself, and a wider set of private and public interests--in support of programs to accelerate private adoption of the new techniques and devices. The list of the objects of such programs, either in effect or seriously proposed, includes the breeder reactor, geothermal energy, new automotive powerplants, electric vehicles, solar heating and cooling, solar electricity generation, and synthetic fuels.

This new set of federal programs raises a number of issues of economic policy, public-private relations, and program analysis and management. This report attempts to identify and explore these issues. We hope to contribute to a clearer view of the context in which such programs must operate, and to identify ways to maximize their contribution to the nation's energy future. The focus is on the "commercial demonstration", which is the mechanism most

commonly used in these programs.

R,D&D as a Component of U.S. Energy Policy

There are two aspects to the energy problem facing the United States. First, there is a national security and foreign policy problem caused by our dependence on a small number of foreign countries for an increasing share of our energy supply. This is a short-term difficulty and, if not corrected, a long-term one as well. Second, the United States (and, in a few more decades, the world) faces the depletion of low-cost resources of petroleum and natural gas. Environmentally acceptable substitutes are much more expensive than oil and gas, and the transition from our current energy system to whatever will replace it is potentially a very painful one. This is a longer-term problem--say on a horizon of 20 to 40 years. Because of the time lags associated with the development, introduction, and diffusion of new technologies, R,D&D programs will not have a significant effect on the national security problem, at least for the next decade or two. Other programs (such as a national petroleum stockpile) can help in that regard. R,D&D programs will reduce imports in the long run, and will reduce the costs associated with the transition to energy resources other than oil and gas.

Unfortunately, these two aspects of the energy problem, and the relevant time horizons, tend to get blurred, and much discussion of the issue is founded on disagreements about the formulation of the problem, on disparities in the way we think about its solution, and on differences in conception of the way the U.S. economy operates now and will operate in the future. There is, in particular, one split in perceptions which is of crucial importance in evaluating new technologies and is often not explicitly acknowledged. On the one hand, much thought and analysis is focused on energy "needs", or "gaps" in energy supply, to be made good by the provision of particular fuels, or by conservation. The concentration is on physical flows. Technologies are rated according to how much can be brought on stream, and how soon, to cover the shortfalls or "gaps". An alternative approach focuses on energy prices as they operate in our market economy. In this view, there is no such thing as an energy "gap": supply is always equal to demand absent price controls and rationing. Some kinds of supply may be less desirable because they are insecure or because they damage the environment. But in all cases the central question is the same: what price are we willing to pay to hold imports down or avoid environmental losses? From this viewpoint the most important fact about a technology is not the extent to which it may "close the gap" but its cost, for it is its cost in relation to price that will determine its contribution, and it is its cost which represents the total real resources it absorbs.

Therefore, a key question is whether the approach via "needs" and "gaps" is appropriate over the next few decades. In the past, energy provision has been left to private markets--some regulated and some not. Energy prices have been the principal determinants of the magnitude and composition of the energy sector, and of energy imports. The driving force has been profits, with government policy measures having a significant influence over what was profitable. Whether this pattern should continue is a matter of some dispute, and only future political events will prove which viewpoint was the more correct for the 1970's.

The hypothesis adopted in this study is that, for the foreseeable future, we are not likely to institute fundamental changes in the structure of the energy sector. Neither are we likely to move in a determined, decisive way to a more centrally-planned energy economy. For better or worse, the market system will predominate in the United States.

In this context, then, what is the role for ERDA's R,D&D programs in meeting the national energy goals? These goals tend to be stated in terms of reducing oil imports. There are two ways to reduce the demand for petroleum: We can lower the demand for energy services (in particular those provided by petroleum-using technologies), or we can substitute other factors of production (capital, labor, and non-energy materials) for petroleum in producing a given level of energy services. R,D&D programs do not directly influence the former. There are several ways to accomplish substitution away from petroleum--for example, by (1) regulation of supply and utilization technology, (2) price controls and financial subsidies, and (3) lowering the cost of substitution of the other factors for petroleum. But again the first two are not in ERDA's hands.

Therefore, the key way ERDA can serve national energy goals may be very simply and starkly stated: it can undertake programs that lower the cost of substitutes for oil, both now and in the future. That is, the basic purpose of the ERDA programs can be seen as the lowering of the cost of substitution of other energy sources or other inputs for oil in the near term, and lowering of cost of transition away from oil to more abundant (or inexhaustible) energy sources in the future. There are two ways in which ERDA can accomplish these ends. The first, and most important, is to support energy R,D&D. By performing such work itself, or supporting it elsewhere, ERDA can change the nature of the technological opportunities, lowering the costs of substitutes for oil. This role is no doubt very important. However, in this paper the focus is on the second way in which ERDA can reduce the cost of substitutes to the consumer. This is to subsidize the introduction of new technologies into the marketplace. As noted earlier, ERDA's chosen instrument for accomplishing this is the commercial demonstration.

Commercialization and the Process of Technological Change

If the United States is unlikely to depart from its long tradition of private markets in the energy sector, then a new energy technology will achieve wide use only if it can meet the test of commercial viability. We can state a simple working definition of necessary conditions for commercialization of a new technology:

> Given: (1) the market prices of labor and material inputs, (2) the relevant cost of capital, (3) the market price of energy, and (4) taxes, legal restrictions on the relevant production possibilities, or other government intervention--then commercialization of a new technology will take place if it is available at a cost that allows the private sector an acceptable rate of return on the capital required.

Only if brought to the point where it meets this condition will a new idea be viable. However, a new technology usually goes through a long process of events in achieving this status. Four rough phases can be identified: invention, development, introduction, and diffusion. Because these activities cost money, and offer no immediate return, the expenditures involved are investments, and each of the steps is usefully thought of as involving an investment choice. That is, at each step the firm acquires a new asset; the asset is expected to yield a favorable return itself, or to open the way to some subsequent investment that will yield a profit. It is the introduction stage and its link to diffusion that is the target of federal programs and proposals in the area of "commercialization."

Several other aspects of this part of the process merit special attention. One is market differentiation. The simple definition given above might be taken to imply that a technology is either "commercial", or it is not. But this would be a misleading simplification of reality. Commercial adoption is not a simple transition from non-use to use; it is a part of the dynamic and complex process whereby a new concept may penetrate some markets but not others, or where the penetration may move at very different rates depending on prices, weather, market structure, etc. Second, energy technologies themselves may present very different challenges at the introduction stage, and the role played by the first plants may be very different. A third consideration is the set of complex adjustments that may be involved in integrating a new technology into a highly developed and interrelated production and marketing system, where the key firms have a structure and personality compatible with the previous product mix.

Thus the term "commercial" really applies to an equilibrium end-state for the process of technological change, and any attempt to influence the pace of the process must deal with a complex transition from prototype to widespread utilization.

To address the role of ERDA in this context, the process needs to be analyzed for reasons why, or areas where, private markets do not automatically produce the desired results. The point of departure for such analysis is the fact that, for the most part, the system generally does work well. The position of the United States as world leader in many if not most fields of industrial technology is a salient indication of this fact. Therefore, an examination of market performance is a first step in the search for projects ERDA might usefully undertake. We focus in particular on failures in the market process at the introduction stage--failures that might be corrected by commercialization programs.

Such a problem, or "market failure", occurs when energy prices do not reflect the value of energy to society. Domestic petroleum prices are determined by a complex interaction of the usual supply and demand forces, and controls imposed by our own and foreign governments. Because the Organization of Petroleum Exporting Countries (OPEC) determines the price of imports, and because imports are the marginal source of supply to the United States, the value of a barrel of oil in the United States is at least the landed price of international crude. However, government price controls hold domestic prices well below this level. Thus a private firm will not obtain a suitable return for introducing a conservation technology which would be economic to the purchaser at the international price but not the domestic price. Natural gas price controls have a similar effect. Given these price controls, there are undoubtedly many cases where government subsidies for the introduction of new conservation technologies would provide substantial social returns.

Moreover, the social value of domestic oil is not determined solely by the international price--there is also the issue of import "dependence". This is a social cost which would not be reflected in private prices even if those prices were not controlled by the government. Since a barrel of oil domestically produced or conserved effectively translates into avoidance of an imported barrel, it is the international price plus the "national security premium" which is the effective social value of domestic supplies. Again, the undervaluation of domestic energy results in a failure in private investment decisions.

In addition to the undervaluation of domestic energy, the special costs associated with the introduction of new technologies into the marketplace can result in a market failure which is concentrated at the introduction stage. Thus, it may be that the proprietary technical and cost information developed at the introduction stage is sufficiently attractive to induce socially desirable outlays, but regulatory and other institutional problems intervene. Important institutional, regulatory, and political issues posed by the new technology may be resolved only by substantial production and use. This is certainly true with respect to some synthetic fuels. Important information about effluent levels of full-scale plants may be inferred from observing pilot plants, for example, but the issue of what effluent levels are acceptable is difficult to resolve until production is attempted on a commercial scale. This is a special kind of distortion of private decision making--investment may be artificially discouraged because society has not gotten around to specifying what rules the new technology will operate under. The pioneering firm must face these regulatory risks, but subsequent firms may not. The nation as a whole benefits from the resolution of the regulatory uncertainties, but the costs are borne by one firm. Thus, a socially desirable introduction may be foregone or delayed.

This circumstance suggests where a well-designed government intervention may be useful. If valuable new technologies are blocked by the regulatory risks, then an off-setting subsidy may be in order. The subsidy would not only encourage use of the technology, which is presumably good in itself, but also lead to a resolution of the regulatory risk and open the way to further, unsubsidized investment. Careful study of the nature of the regulatory problem should, once again, offer guidance as to what kind of subsidy will most effectively resolve the issue.

Other possible sources of market failure are the non-appropriability of technical results, problems of market structure, and excessive risk aversion in private firms. Any of these may be relevant in a given circumstance, though it does not appear that they often will be important. Patents, and the advantages of being first to introduce a new technology, generally allow pioneering firms to capture the major share of the benefits from technical improvements in introduction. The impact of market structure on technological innovation is not well understood, and it is unclear that there is any _a priori_ reason to assume that the introduction of new technologies is inhibited in this regard.

Finally, the nation's capital markets are generally considered to be reasonably efficient at spreading of risk, so in general it is reasonable to assume that investments in profitable new technologies will be forthcoming.

It is problems in energy pricing and the non-appropriability of the resolution of regulatory risks that are most likely to be the sources of socially erroneous investment decisions on the introduction of new energy technologies.

Goals and Means of Government-Supported Commercial Demonstrations

The principal purpose of ERDA's commercial demonstration programs, then, seems reasonably clear: ERDA should subsidize the introduction of socially profitable new energy technologies to the extent that they are being impeded by low energy prices or by high regulatory uncertainties whose resolution would be of value to more than one firm.

However, ERDA must perform this function within an environment which is not under its control. Specifically, energy prices are determined by a combination of foreign governments, higher level policy decisions of the U.S. government, and market forces. As we have discussed, technological change is the result of a series of investments, investments which are made in the expectation of a suitable return. Expected prices are the key parameters, external to the firm, which affect the investment decisions. In the early stages of the process, the relevant expected prices are those several decades in the future. At the introduction stage, however, the relevant prices, in relation to expected costs, are crucial to the investment decision, and they are not changed by a commercial demonstration program.

Thus, in most cases the long-run commercial potential of a new technology will be relatively independent of possible interventions by ERDA in the introduction stage. This is because, in most cases, the costs of the introduction stage which are not recovered _during_ that stage, are a small fraction of the total cost of the product _after_ introduction. Therefore, most technologies which appear to be commercial in the long-run, will be introduced and "commercialized" by the private sector. In most cases, ERDA commercial demonstration programs therefore simply do not have very much leverage. They may be useful, but they are not often likely to be decisive in determining the fate of a new technology.

Even where it appears that a government-supported commercial demonstration can perform the sort of useful social function described here, one must be sure that these expenditures are the most efficient method. In fact, government-supported demonstrations attempt to reduce technical and institutional uncertainties with what might be termed a "brute force" technique. In many cases the resolution of the relevant technical and institutional uncertainties may not require the actual construction of commercial-scale plants. For example, an obvious alternative for resolving legal and regulatory uncertainties is direct intervention in the public decision-making process in support of expedited action. This could take the form of requests or orders to regulatory or legislative bodies, or studies which would provide the key data necessary for resolution of regulatory problems. While it is not clear that such activities will necessarily be less expensive than the net cost of a commercial demonstration, such alternatives should always be considered.

Whatever the details of the specification, the goals of a demonstration program imply criteria for the choice of public instruments. We have argued that the purposes of government-supported commercial demonstration projects are principally to support the development of the information associated with the resolution of the technical and institutional uncertainties concerning new energy technologies, and to provide a subsidy to foster the introduction and widespread use of technologies faced with inappropriate energy prices. With these goals in mind, some general considerations of program design can be laid out.

Both goals lead immediately to a concern that the commercial demonstrations be conducted in such a way as to simulate the normal workings of the private sector--i.e., the influence of the subsidy should be as small as possible beyond the obvious fact that it is lowering the cost of the actual demonstration to the firms involved. This implies that the participants in the program should be those who would be dealing with the technology under circumstances of widespread use, and that the incentive structure associated with their participation should be as "realistic" as possible.

The incentives to private participants will be strongly dependent on the actual mechanism used to deliver the subsidy. Ideally, the mechanism should provide project managers with a circumstance which looks the same as that which they would face in the unsubsidized case. This is important with respect to the choice of inputs--especially capital as compared with labor, transportation, maintenance, etc. The incentives with respect to risk-taking also should be as realistic as possible.

Finally, financing mechanisms should reveal the full costs of the program and the detailed cost performance of individual technologies. There will of course be large uncertainties in estimates of both the costs and benefits of such programs, but some financing methods allow greater visibility than others. Clearly, if the extent of the subsidy is not well known, then the true cost will not be readily calculated from the product prices. If this is the case, then uncertainty of major significance will remain.

Many forms for government subsidies have been proposed for commercial demonstration programs. These include tax expenditures, direct government operation, price guarantees, loan guarantees, and the rolling-in of demonstration costs with other costs in the special case of regulated industries. We did not analyze each of these possibilities in the detail they deserve. The key criteria of visibility of subsidy costs and minimal distortion of factor input prices point immediately toward specific project-by-project price supports, which fare well against both criteria. The two criteria similarly point away from the use of loan guarantees--their value is difficult to calculate, they subsidize capital as opposed to other inputs, and they distort incentives for follow-on investments.

Evaluation and Planning

The concepts used here provide a framework for analyzing commercial demonstration programs. However, the leap from qualitative concepts to detailed quantitative calculations is long and uncertain, and we have much to learn about the market processes we must analyze. As a first step in laying out the evaluation program, an evaluation scheme must focus on the probability distribution of the cost of energy saved or produced by the technical option under consideration, should it attain wide-scale usage. This function summarizes at any given time the set of expectations for improvements which would result from investments in R,D&D as well as the technical and institutional uncertainties which might affect the option. The relationship between this function and similar sets of expectations concerning the market price and social value of energy are at the core of the analysis of the likelihood of

<u>private</u> investments in R,D&D on the option and the <u>desirability</u> of <u>public</u> investments.

Our development of the evaluation problem points to the identification of several areas of analysis and forecasting which are crucial to the evaluation of schemes of federal intervention in commercial demonstration. All analytical efforts which attempt to evaluate national income benefits from this type of investment must deal with these issues in one way or another. In each case the available techniques allow analysis to take place but similarly in each case substantial improvements are needed to raise the level of confidence we can place in such analysis. Thus, these key areas comprise an agenda for future research to improve our ability to analyze government investments in energy R,D&D and commercial demonstration in particular.

First, there is a need for price forecasts--both market prices and social values. Such forecasts ultimately depend on analysis of international oil markets, on the tariff or other policies that may be used to buffer the U.S. economy from these prices, on the process of price formation in product and regional markets throughout the economy, and the value to be placed on energy independence.

Second, the evaluation of the benefits of the accelerated introduction of new technologies depends ultimately on forecasts of the rate of diffusion of those technologies through the relevant markets. In general, this requires a set of analyses of transportation, processing, and energy technology choice which can simulate the way the economy adjusts to a new technology, given that the technology has been demonstrated in the introduction stage to offer cost savings. For example, modeling efforts at Stanford Research Institute (originally for Gulf Oil Corporation), and Brookhaven National Laboratory provide a framework for conditional forecasting of the expected penetration of new and emerging energy technologies and products based upon engineering information concerning the cost and efficiency attributes of these technologies.

However, two significant problems are not addressed by either of these models, or by most other, less formal, studies of these circumstances. First, we would expect that the actual commercial availability of a new technology will depend critically not only on the level of prior R&D activity, but also on market factors. Thus, an analysis which purports to explain the penetration of new technologies must also explain the evolution of circumstances which lead to the availability of those technologies at a point in time. This is an extremely difficult research issue. A second, and closely related issue, concerns the demand for these new technologies. Simple studies of consumer behavior based upon simple cost considerations are probably not adequate to characterize consumer response to a new product or technology. The problem is essentially one of using information on consumer response to existing technologies to project their reactions to technologies and products which they have not yet observed. Both the issues of technology availability and consumer demand for new technologies are not addressed in the SRI-Gulf and Brookhaven models, nor by any other formal studies of energy technology choice with which we are familiar.

Third, a key component of any analysis will be the estimation of the likely investments in R,D&D that would take place without government intervention. For example, it may be that government subsidy only substitutes for industry investment that would take place in any case, or that it only speeds up the introduction process by a period of a few months or a year or two. This once again leads back to a need for a clearer understanding of the nature of the market process of technology development, how it serves the social good, and how one might gather information about likely industry involvement at the introduction stage for different types of technologies.

The fourth key link is the estimation of the impact of the government-supported commercial demonstration. That is, it is necessary to understand and describe how the distribution function for ultimate costs will be affected by an introduction into the marketplace.

Finally, it is necessary to understand the costs and effects of the different instruments for supporting commercial demonstration. The alternative instruments that may be used by the government to subsidize the introduction stage may have very different costs. Different instruments may have distinct effects on the amount of learning that takes place in the introduction stage. In order to choose among types of programs, one needs to be able to distinguish between the available instruments and their ability to produce a good measure of the technical option's costs. But to know the option's cost in a situation where government subsidies are present, the total cost of the subsidy must be known; this is a difficult problem in and of itself.

These issues of evaluation provide a challenging set of topics which should rank highly on the national agenda for policy research. It seems clear that government programs aimed at accelerating the pace at which new technologies become available and are utilized will absorb an increasing share of public resources over the coming years. Our mixed capitalist economy responds to such interventions in complex ways that analysis can serve to illuminate, so that the public good can be served in the most effective and efficient manner.

1. INTRODUCTION AND BACKGROUND

The federal government has set out to develop new technical options for the country's energy sector. However, unlike most previous public R&D efforts--especially those in defense, space, and war-time production--the government is not simultaneously the customer for the results. There is no doubt that the long-run measure of the success of the U.S. Energy Research and Development Administration (ERDA) will be the degree to which its new technologies see actual application. But under current policy and well-established tradition, the ultimate technology choices will be left to private corporations and the normal operation of our mixed capitalist system of economic organization. This circumstance, coupled with a strong concern over mounting dependence on oil imports, naturally leads to an attempt by federal authorities to increase the rate at which new technologies are adopted. This is being done through greater federal involvement in "commercial demonstrations" and other "commercialization" schemes to help the introduction of new energy technologies.

It is our purpose (1) to explore the issues that arise in connection with government attempts to use commercial-scale demonstrations to spur technological change, (2) to review what is known about the economic and industrial processes that are involved, and (3) to probe critical areas of ignorance in an attempt to formulate an agenda for research in this area. We have placed a high value on recording well the "facts-of-life" as we understand them.

1.1 PAST AND PRESENT GOVERNMENT ACTIVITIES IN SUPPORT OF TECHNOLOGICAL CHANGE

The federal government has long been involved in supporting technological change in the United States. In the past most of this support has fit into three categories. One category is the development of systems which are part of the government's own procurement needs. The bulk of this effort has been in the areas of military and space technology. Much of modern civil aircraft technology has come out of this activity, even though it was not an explicit goal of the government's R&D programs.

The second category is the support of basic and applied research, with the goal of advancing technology across a broad front, in support of particular economic sectors, national defense, or the growth of the economy as a whole. Federal investment in agricultural technology has a long history; other efforts grew out of the World War II experience, and have been carried out principally by the National Science Foundation and the research offices of the military services. The distinguishing feature of this support has been the fact that the private sector was free to develop and employ the new technology according to its own decision-making mechanisms. Generally, government support for technology for civilian use was stopped when it was ready for incorporation into prototype products.

A third category has been important at times. This is government support for the development and use of new technologies during war-time. A notable example is the federal financing of the final technical development, and the extensive production, of synthetic rubber during World War II. As discussed in Appendix E, much of the basic science and technology of rubber synthesis was available at the beginning of the War. It had not been put to commercial use because the cost was substantially greater than the price of natural rubber. When natural rubber supplies were cut off, the government commenced a massive program to construct synthetic rubber plants, utilizing a number of different technologies. In this case the government was not the principal purchaser of the product. However, it is distinguished from the current circumstance by the extensive war-time government controls over important sectors of the economy--setting prices, allocating raw materials and intermediate goods, etc. So the infant synthetic rubber industry could hardly be considered "commercial" under the definition used in this study.

The more recent programs and proposals under study here are different from these earlier experiences of federal involvement in R&D. In the energy sector, government action is being undertaken explicitly for the purpose of supporting the commercial application of new technologies. The technologies at issue may or may not have been developed under government support, but at any event the government is not the buyer of the product. The technologies are to be utilized by the private sector.[1] Commercialization programs were embodied in legislation supporting the introduction of solar heating and cooling and geothermal energy, which became law in 1974.[2] The most prominent

---

[1]As discussed in a recent Rand Study, ["Analysis of Federally Funded Demonstration Projects" (The Rand Corporation, Santa Monica, California, April, 1976), Reports R-1925-DOC, R-1926-DOC, R-1927-DOC], there have been some programs of this sort in the past. The most prominent are the civilian application of nuclear power for electricity generation, discussed by Rand, and the development of the civil supersonic transport, discussed in Appendix D to this report.

[2]PL 93-409, "The Solar Heating and Cooling Demonstration Act of 1974"; PL 93-410, "The Geothermal Energy Research and Development Act of 1974"; and PL 93-430, "The Solar Energy Research, Development, and Demonstration Act of 1974."

and, if it had become law, by far the largest, would have been "Synthetic Fuels Commercialization Program." The program was proposed by the Administration.[1] As reported out by the House Committee on Science and Technology,[2] the program would have entailed U.S. government loan guarantees and/or price supports for synthetic fuel plants producing the equivalent of 200,000 barrels of oil per day; $4 billion in loan guarantees would have been authorized.

This is the type of program we examine in this paper. However, our attention has not been limited to the solar, geothermal, or synthetic fuels proposals. Because it appears that there will be an increasing number of government-supported commercialization programs, we have attempted to focus on the general issues associated with the government-supported commercialization of energy-related technologies.

1.2 THE FOCUS OF THIS STUDY: ERDA'S COMMERCIAL DEMONSTRATION PROGRAMS

In a study of federal "commercialization" activities there is a temptation to focus discussion on overall national energy goals and on the full range of policies that affect the energy sector. In particular, one of the most important influences on the viability of new energy technologies is the effective market price of energy--which is determined by policies regarding import quotas or tariffs, price controls, widespread subsidies or taxes, etc. Here however, we do not focus on efforts to change the long-run market situation for a new technical option, but rather on those activities aimed at

---

[1] "Recommendations for a Synthetic Fuels Commercialization Program," Synfuels Interagency Task Force, 1975, Four Volumes.

[2] "Loan Guarantees for Demonstration of New Energy Technologies," U.S. House of Representatives Report No. 94-1170, May 16, 1976.

getting an option into widespread commercial utilization within a given market environment. This is a realistic limitation because by and large the national policies that determine price and market conditions are made independently of their impact on any particular class of new technical options. This restriction holds with particular force as we analyze decisions by ERDA, which has statutory responsibility for the research, development, and demonstration (R,D&D) of new technical options, but not for the long-run conditions which comprise their marketing environment.[1]

ERDA's principal tool in its commercialization programs is the government-supported "commercial demonstration". That is, ERDA may subsidize (or perform itself) the first "commercial-scale" utilization of a new technical option. "Commercial-scale" may be roughly defined as the minimum scale which would be used if the option were being introduced into the marketplace by the private sector without government support. A distinguishing feature of the commercial demonstration (and the source of much confusion) is that the net revenues from sales of the product of the demonstration are likely to return a substantial fraction of the total investment required.[2] This is in contrast to the more common government-supported demonstration, which is generally at smaller scale and uses technology less well developed.

---

[1] In the case of technology-specific subsidies, taxes, or regulations, the decision to utilize them would obviously not be made independently of the state of the technology, but even in this case ERDA does not have the relevant responsibility (cf. FEA/ERDA Memorandum of Understanding, April, 1976). The case is similar for other technology-specific governmental controls, such as environmental regulations.

[2] The confusion arises because production is not the principal purpose of the demonstration. Rather, the goal is to clarify the crucial uncertainties associated with the new technical option. This is addressed below at some length.

1.3 ORGANIZATION OF THE STUDY

Because the current and proposed commercialization activities are unprecedented in their complexity and scale, and because the overall energy policy of the country is in a continuing state of flux, it is necessary to begin this discussion with a statement and interpretation of the broad energy goals that have been set by the Administration and Congress. This is undertaken in Section 2, and an attempt is made to take these broad statements and re-phrase them into an operational definition of targets for federal activities in the area of commercial demonstration. A fundamental problem facing the agency is the estimation of the market conditions under which the substitution of new technologies is expected to take place, and this is addressed.

Section 3 considers the role of the federal government in changing the technology of energy supply and utilization. To set the context for subsequent discussion, a brief description of the process of technological change is presented, and an attempt is made to define where the point of "commercialization" is supported to occur. Given a brief description of the process, attention is turned to various flaws or "failures" in that process and to the role of federal intervention.

Section 4 then examines the goals for commercial demonstration programs in particular, and the means for attaining them. The economics of the commercial introduction process is first discussed with a focus on the circumstances where government-supported commercial demonstration projects are likely to be effective. The goals of commercial demonstration projects also may be met by other means at ERDA's disposal; these circumstances are examined as well. There follows a discussion of the political, legal, and instititional problems of commercial demonstration projects; even given a sound economic basis, the implementation of such projects faces substantial difficulties.

Finally, the specific policy measures for supporting commercial demonstrations are addressed. A detailed review and analysis would be beyond the scope of this study. Therefore, we have addressed the general criteria which should be considered, and examined only one of these tools (i.e., loan guarantees) in any detail.

Finally, in Section 5 we apply the general principles developed earlier to an analysis of the problem of project and program evaluation. The discussion becomes somewhat more formal at this point, as the nature of the investment in a commercial demonstration project is examined. Section 5.3 focuses on our key areas of ignorance, and comprises an agenda for research in this vital policy area.

2. R,D&D AS A COMPONENT OF NATIONAL ENERGY POLICY

2.1 THINKING ABOUT THE ENERGY PROBLEM: GAPS OR PRICES?

Three years after the oil embargo there remains wide disagreement about the nature of the energy problem. Some see a fundamental shortage of resources; others argue that it is primarily a matter of national security. The origin of the problem is variously attributed to the manipulations of oil companies, to too much government interference in private markets, or to insufficient federal action and too little support for new energy technologies. For some observers the answer is found in new energy sources and in technological change; for others the only solution is a fundamental revision in the values and life-style of American society. Naturally, these diverging views lead to calls for a variety of conflicting federal actions. The lack of consensus has been debilitating to the efforts of the Administration and the Congress, and of private parties, to achieve a coordinated and vital energy policy.

One split in viewpoint is especially important to discussions of federal energy programs. So much misunderstanding and real difference of opinion stem from divergence on this issue that it is important to begin with a clear statement of the approach taken by the authors of this study. The issue concerns the character of the energy "crisis" and the proper way to formulate solutions to it. On the one hand, much thought and analysis is focused on energy "needs", or "gaps" in energy supply, to be made good by the provision of particular fuels, or by conservation. The concentration is on physical flows. Technologies are rated according to how much can be brought on stream, and how soon, to cover the shortfalls or "gaps".

An alternative approach is to focus on energy prices as they operate in a market economy. In this view, there is no such thing as an energy "gap": supply is always equal to demand absent price controls and rationing. Some kinds of supply may be less desirable because they are insecure or because they damage the environment. But in all cases the central question is the same: what price are we willing to pay to hold imports down or avoid environmental losses? From this viewpoint the most important fact about a technology is not the extent to which it may "close the gap" but its cost, for it is cost in relation to price that will determine whether it makes any contribution at all.

The difference in viewpoint is fundamental. Usually it is not a divergence of ideology. Rather, it is a difference in perception of how the U.S. economy actually operates, of the driving force behind changes in the energy sector, and about what policy tools are going to be applied. If the circumstance is formulated in terms of "needs" and the failure of assured supply, then the task of government is to find new supply and utilization technologies, design and build them, and ensure that they are used. This is the way energy is managed in the centrally-controlled economies (where the "needs" approach is called the method of "energy balances"). If the policy tools are available and the society wills to use them, then the view is perfectly appropriate. By consensus many services are provided that way in this country--e.g., postal service, highways. Such an approach was successfully and appropriately used for the planning and subsequent provision of key commodities during World War

II. As discussed in Appendix E, the "gap" left by Japanese control of natural rubber supplies was successfully closed by government-supported production, supplemented by detailed regulation of the importation, pricing and utilization of available synthetic and natural rubber supplies.

The issue is whether the approach via "needs" and "gaps" is appropriate with regard to the United States over the next few decades. In the past, energy provision has been left to the workings of private markets--some regulated and some not. Energy prices and the relation of those prices to the costs of domestic supply and conservation measures have been the principal determinants of the magnitude and composition of the energy sector, and of energy imports. The driving force has been profits, with the government as one of the determinants of what was profitable.[1] Whether this should continue is a matter of some dispute. Perhaps the national security problem presented by oil dependence requires a drastic change. Perhaps the prices implied by a commitment to energy independence are socially intolerable because of the potential impact on life-style and on the income distribution. If so, technological change may relieve this squeeze by producing energy at costs lower than otherwise available. If the new technologies did not prove competitive then they would need to be subsidized, and more government direction of energy markets would serve this end.

The hypothesis adopted here is that for the foreseeable future we are <u>not</u> likely to institute fundamental changes in the structure of the energy sector, or move in a determined, decisive way to a more centrally-controlled energy

---

[1]For example, while leaving most investment and operating choices to the private sector, public policy has had a great effect on the oil sector through various financial incentives, such as the foreign tax credit and the depletion allowance.

economy. For better or worse, the market system will predominate in the U.S. In fact the very word "commercialization" presumes that the market system will predominate in the energy sector.

If private markets will pervade the energy sector, then "gap" analysis (which tends to ignore prices and profits) involves analytical and planning tools, and more importantly, policy prescriptions, that are inconsistent with the facts of our economic organization. "Commercial demonstration" of new technologies, either supply-augmenting or demand-diminishing, can lead to economically viable new industries only if the expected price regime which these technologies will face provides the incentives for investments to bring them forth. When the role of prices is ignored, the policy goals seem to be those of reducing uncertainties regarding costs of the new technologies. The implicit assumption is that when the new technologies are demonstrated as technically feasible and the uncertainties regarding costs and productivities are "eliminated", commercial penetration is assured. In fact, these activities may have very little to do with commercial potential, unless one imagines a massive increase in government direction of energy markets.

2.2 NATIONAL ENERGY GOALS

Against this viewpoint, we may contrast recent proclamations of national energy goals. As stated by the current Administration, these goals are heavily related to national security, and to the holding down of energy costs to the American consumer. Three main policy goals were put forth in the 1975 State-of-the-Union message and reaffirmed in the 1976 Energy Message:

--"First, to halt our growing dependence on imported oil during the next few critical years.

--"Second, to attain energy independence by 1985 by achieving invulnerability to disruptions caused by oil import embargoes. Specifically, we must reduce oil imports to between 2 and 3 million barrels a day, with an accompanying ability to off-set any future embargo with stored petroleum reserves and emergency standby measures.

--"Third, to mobilize our technology and resources to supply a significant share of the free world's energy needs beyond 1985."

In additon, the Administration has enunciated a set of principles that are to guide the development of the program:

--"Provide energy to the American consumer at the lowest possible cost consistent with our overall economic goals.

--"Make energy decisions consistent with our overall economic goals.

--"Balance environmental goals with energy requirements.

--"Rely upon the private sector and market forces as the most efficient means of achieving the Nation's goals, but act through the government where the private sector is unable to achieve our goals.

--"Seek equity among all our citizens in sharing of benefits and costs of our energy program.

--"Coordinate our energy policies with those of other consuming nations to promote interdependence, as well as independence."[1]

The three main policy goals are stated in terms of physical quantities and, following the argument laid out above, one's view of the task of a federal energy R,D&D agency is strongly conditioned by the seriousness that is attached to these physical targets. If the import "gap" <u>must</u> be closed to 3-to-5 million barrels per day by 1985, then the task of an R,D&D agency is clear: prepare the technologies to close the gap, at minimum cost, as with

---

[1]These goals and guidelines are discussed in "A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future" (ERDA, April, 1976), ERDA Report No. 76-1.

military procurement. Moreover, it is not unreasonable for R,D&D managers to assume that the necessary federal regulations and directives to employ the new technologies will be forthcoming "where the private sector is unable to achieve our goals". Else the goal would not be stated so starkly.

On the other hand, if one assumes that the country is not likely to institute a major shift toward government direction of energy supply and utilization, then more attention must focus on the traditional forces that have moved the energy sector--prices, costs, and profits. One's political judgment may be that, for the people and Congress, the goal of 1985 imports at half the current level is not so important as to override other aspects of federal policy and well-established tradition. Or, one may feel that such a goal (and the use of federal programs to attain it) is simply wasteful; the price is too high, particularly considering alternative methods for ameliorating the security problem. Either way, rather than formulate the issue in terms of strict quantitative targets one will tend to think in terms of prices, and of an objective of lowering the costs of new technologies.

Of course, in focusing so closely on the real flows of oil and their costs, there are subtleties in the R,D&D policy that may be overlooked. In particular, there may be significant international and political aspects in the medium term, say through 1990, even though the direct effect of "commercialization" efforts on oil imports will be quite small. Thus, there apparently is some hope that merely signalling our intention ultimately to reduce U.S. dependence on Arab exports will influence the psychological environment of international diplomacy so as to reduce the leverage and bargaining power of the Arab states. The room for American initiative will be increased, and the likelihood of Arab nations taking (or threatening) actions inimical to

American interest will decline.

There is another related point. The dependence on our Japanese and European allies on Arab oil is much greater than that of the U.S. itself; this is true now and will continue in the future. Under the assumption that the economic strength and foreign policy orientation of these allies will be no less important in the future than they are now, the resistance to coercion of Europe and Japan is also an important foreign policy objective for the U.S. Yet there is no prospect of these nations, as a group, reducing their relative dependence on oil imports to even the present U.S. level, which is widely considered to be unacceptably high. Thus, even with zero imports to the United States, we would be far from true "energy independence."

Of course, what people believe may be as important as the facts of the matter so far as understanding developments in federal policy are concerned. The ability of the United States to retain its position of leadership in international negotiations over energy and related issues of the world's distribution of income and power will depend in part on perceptions of America's willingness to make major commitments to solve its own energy problems. In these complex international processes, the commercialization activities may play an important symbolic role.

Doubtless, much of the history of these programs, especially the synthetic fuels commercialization program, has been influenced by this aspect. Unfortunately, ambitious-sounding programs, widely publicized internationally, can reduce U.S. credibility if they come to be seen as mere words. The national policy of "Project Independence", as declared in the crisis months of 1973-1974, is now widely discredited abroad (as well as at home). At that time the government policy was that world oil prices were "too high" and that a combination of domestic and foreign policy would bring them down. They have risen by nearly 50 percent since then.

Based on these observations, we may accept the broad sense of the goals stated above, but we may want to revise the language somewhat. First, we have a national security problem which is created by the fact that we import a large fraction of our petroleum from a small group of countries. One goal is to reduce this insecurity, perhaps by lowering the demand for imports in the short run and by avoiding high import levels in the future. Presumably there is some domestic cost beyond which we would not go in attempting to reduce imports, for at some level there are other, less expensive ways to deal with the security problem (e.g., more extensive storage schemes).

Second, there is a longer-run problem of the transition from oil and gas to other energy sources. The government does well to be concerned with this transition quite apart from the national security problem. Once again, the goal can be stated in terms of powering the demand for energy in the longer term, though presumably not at any price.

2.3 MEANS OF MOVING TOWARD NATIONAL GOALS

If we may accept this more general description of the goals of policy, then we may proceed by noting that there are two ways to reduce the demand for oil:

(i) Lower the demand for energy services, in particular those services involving petroleum-using technologies. As delivered energy prices change, the demand for energy services will be affected. For example, higher gasoline prices will reduce the vehicle miles traveled (all else held the same).

(ii) Substitute other factors of production for petroleum products in producing a given level of energy services. Such factors include both other primary energy sources, and other factors of production (capital, labor, and other material inputs).

Factor substitution may take place either through regulation, or changes in relative factor prices. Examples of important substitutions which could be induced either by regulation or price changes include using coal and/or nuclear power to replace oil in base-load electric power generation, or the use of coal in place of petroleum products as a boiler fuel in operating petroleum refineries. Capital and labor may also be substituted for petroleum in boiler use, for example, through more frequent inspection and maintenance of boiler equipment, and by the installation of more elaborate monitoring systems for detecting leaks.

The substitution process works both ways, of course. As oil prices fell over the past few decades, there was a shift away from coal and wood to oil. Later, with the extension of pipelines, the same process occurred for natural gas. Also, with falling energy prices, consumers substituted energy for other inputs and dropped the use of energy-saving methods. For example, as discussed in Appendix B, the use of recuperators for capturing the heat in stack gases was common in the early part of the century, but this device disappeared from many industries as the price of energy fell (relative to capital) over the intervening decades. If relative energy prices rise, the reverse process takes place.

Three types of government actions may influence the process:

(1) Regulation of supply and utilization technology: For example, this might involve rules against installation of oil-fired burners, the 55 mph speed limit, or energy-conserving building codes for new residential and commercial demonstration.

(2) Price controls and financial subsidies: Government policy influences substitution by affecting the relative prices of factors of production.

(3) Lowered costs: The government may take measures which lower the supply costs of factors competing with oil, thereby encouraging substitution.

But items 1 and 2 above are not in ERDA's hands. Moreover, it is not likely that the federal government will undertake major revisions in the nature and degree of federal direction of energy markets through large-scale efforts at technology regulation or wide-scale subsidy programs.

Therefore, the key means by which ERDA can serve national energy goals may be very simply and starkly stated: Lower the cost of substitutes for oil, both now and in the future. That is, the basic purpose of the ERDA programs can be seen as the lowering of the cost of substitution of other energy sources or other inputs for oil in the near term, and lowering the cost of transition away from oil to more abundant (or inexhaustible) energy sources in the future.

The first and most important way to do this is to support energy R&D. By performing such work itself, or supporting it elsewhere, ERDA can actually change the nature of the technology trade-off. By making new technological options available, ERDA can actually lower the true costs of substitutes for oil.

In this paper, however, we focus on a second way in which ERDA can reduce the cost of substitutes--i.e., to subsidize the introduction of new technologies into the marketplace. Generally before commercial-scale usage of a new product or process is undertaken, the major technical uncertainties associated with it have been resolved. On the other hand, many of the details which will ultimately determine its real cost may remain to be fixed. Thus there often are substantial introduction costs, which must be borne by some pioneer firm, or firms, before the new option can achieve widespread adoption. These introduction costs are most often associated with the lowering of the technical, institutional, legal, and regulatory uncertainties associated with large-scale production and widespread usage. ERDA's method for giving this subsidy has been the commercial demonstration. Through subsidized commercial demonstration, ERDA lowers the costs of substitution, and therefore indirectly reduces the cost of the substitute.

Needless to say, this is a very roughly summarized view of what ERDA can do. It is useful to have even such a crude conception, however, when discussing the issue of commercial demonstration, for it is this aspect of ERDA policy that most dramatically raises the question of the process by which new technologies are adopted in the economy and of the difficulty of any attempt to affect the direction and pace of this technological change.

2.4 THE PROBLEM OF THE "PLANNING PRICE"

Through R,D&D the federal government is undertaking to develop new lower-cost technologies for adoption in private markets. Where there are special problems at the point of market introduction, ERDA will use the mechanism of commercial demonstration to try to accelerate market penetration. Naturally, for each technology, there is some set of market conditions that will have to be met. There are several aspects of energy markets that are relevant, but the most important is the energy price itself. For technologies that promise to achieve a cost below expected market prices, there is a reasonable expectation that the substitution discussed above will take place. For those with less promise for cost reduction there is no such expectation. Of course, ERDA's mission is to find and support the technologies that offer promise of being competitive, and to do this there must be some notion of what price is appropriate for the analysis and selection process.

As one looks forward to the adoption decisions by private firms, there are other factors besides expected price that are important. For example, the risk perceived by a firm contemplating investment in a new technology is affected not only by the expected future prices but by expectations about the rules or procedures by which those prices will be set. It is one thing if prices are expected to follow, more or less, the developments in world energy markets; it is quite another if there is a prospect of continued domestic price controls (or selective subsidies), or of an active tariff/quota policy, even if the expected price is roughly the same. A policy of more widespread regulation of rates of return represents yet another state of future markets, and the calculation of the viability of particular technologies might be different yet again.

Thus, in order to allocate its resources efficiently, ERDA is faced with a continuing problem of determining an appropriate set of likely prices, and other market conditions, which its technologies must confront in future years. The incorporation of these considerations is particularly important in the evaluation of commercial demonstration programs, where the hope is that the technology will prove profitable (as perceived by private market calculations) at the completion of the program. Today many domestic energy prices are being held down by price controls, even below the cost of imports. There has been discussion of a tariff floor, to protect investments against the risk of failure of the oil cartel, but no policy has been set. Similarly, long-term subsidies for specific fuels have been proposed, but the issue is not resolved. Even the fundamental structure of energy supply industries--private versus public ownership and development, or the regulation of rates of return--is the subject of serious questioning, particularly in the area of new bulk supply technologies.

Thus, in anticipation of increases in energy price, ERDA may carry new technologies to commercial-scale demonstration and even subsidize the first one or two plants in order to avoid delay in working out critical technical problems and institutional barriers. But then two disturbing questions emerge:

(1) Where does the process of demonstration end and that of longer-term subsidy begin, and how far along this process should ERDA carry its activities? At present, ERDA has no mandate to carry out long-term subsidy programs.

(2) What targets, in terms of expected price and other market conditions, should ERDA be striving for with each of its technologies? Clearly the proper timing of expenditures on particular types of technology, and the allocation among different technologies, depends on the likely future trajectory of energy price and energy sector organization. But these market conditions are being set for a host of reasons other than their influence on substitution in the energy sector.

It is not clear to what degree ERDA has a responsibility or a mandate to try to override or correct for the results of domestic price control policy, or to try to influence the other market conditions that influence the attractiveness of various technologies. It also is not clear what future conditions ERDA should be anticipating in planning its programs, so that reasonable success in lowering the costs of different technologies actually produces results at critical times along the way. This is an issue that clearly calls for further investigation and clarification, and for the development of improved methods of analysis.

Here we call attention to the issue of future market conditions by focusing on two energy prices which ERDA must establish in order to evaluate R,D&D projects. One is a "planning price" which, as discussed above, is the likely effective market price of the relevant energy form. More specifically, it is the actual energy price in private markets, including the effects of the relevant government modifications to those markets. This would include whatever subsidies are applicable to a particular technical option. Of course, this is a future price--so it must reflect ERDA's expectations for future conditions of supply and demand, and forecasts of goverment intervention. Obviously a single price will not match the gross complexities discussed above; in reality some probability distribution will be required and the distribution will be different for the various energy options.

A second "price" with which ERDA must deal is one that may or may not actually appear in energy markets. It is the social value of energy--the amount the society should be willing to pay for one more unit of a given energy source. Of course, it would be the best of all worlds, at least with respect to economic efficiency in the energy sector, if these two prices were the same. However, for reasons we have already discussed, and will address further below, this condition does not appear to hold now and is not likely to do so in the future. Some measure of the social value of energy is necessary for the evaluation of R,D&D programs, however, for it provides a basis for determinating whether investment in a new technical option is socially profitable.

We return in Section 5 to address more general issues of project evaluation. First, however, it is necessary to review the process by which substitution of new technology takes place, and to put the particular activities of commercial demonstration into perspective within the wider context of the behavior of American industry.

3. "COMMERCIALIZATION" AND THE PROCESS OF TECHNOLOGICAL CHANGE

When we speak of a society's "technology" we refer to the ability to combine capital, labor, and other inputs in the production of goods and services. At any point in time this technology is embodied in the latest capital goods, the skills of labor, and the collective knowledge of how to combine them. By a change in technology it may become possible to produce more of a given good or service from a fixed set of inputs (a change in process) or to produce some totally new product. If input prices hold constant, then a process innovation lowers the cost of the product.

A change in technology has no effect, however, unless it becomes a change in "technique", by which we refer to that combination of input factors and knowledge which is actually in use. When a previously unused but known technology is brought into use, there is a change in technique which is not a change in technology. Recent changes in energy prices have yielded many examples of such changes in technique alone--leading to the substitution of capital, labor, and other inputs for energy. There also are examples of changes in technology that have been (or will be) incorporated as changes in technique. It is this latter type of change that is our concern in this study, with a special focus on changes that facilitate substitution away from the use of petroleum.

It was argued above that the United States is not likely to depart from its long tradition of limited government intervention in the energy sector, and that therefore a new energy technology will achieve the status of a widely-used technique only if it can meet the test of commercial markets. As a starting point, then, it is useful to state a simple definition of the necessary conditions for commercialization:

> Given: (1) the market prices of labor and material inputs, (2) the relevant cost of capital, (3) the market price of energy, and (4) taxes, legal restrictions on the relevant production possibilities, or other government intervention--then commercialization of a new technology will take place if it is available at a cost that allows the private sector an acceptable rate of return on the capital required.

While this simple definition may apply in markets at equilibrium, it defines only the end point of the process of technical change, and it is this process which will draw our attention here. A new technology must be brought to the point where it meets the above criterion, or it will not ultimately be viable. This is the fundamental hypothesis of a study of the "commercialization" of new technologies, given that a centrally-directed energy sector is not anticipated.

The interesting questions, then, revolve around the way this process of technical change actually seems to work now, where it may fail to serve the goals of the nation, and what corrective measures are available. Such an inquiry helps highlight where government efforts are best put; it also brings an appreciation of the limits of what can be achieved by the types of programs now contemplated.

In the sections that follow we review the process of technical change as it occurs in a sequence of corporate (and perhaps public) investments. Much of the discussion is little more than a repetition of the "facts of life" as we now understand them, but such a survey helps orient subsequent analysis of the role of government in facilitating the process.

Implicit in our discussion is the assumption that most of the new technologies which are likely to be commercialized in the foreseeable future will not be "radical" innovations, but will be improvements which are more incremental in character.[1] While this assumption is not often constraining (as will be seen) it influences our treatment of the economics of the process of technological change. Pocket calculators may be considered a recent radical innovation; shale oil is an example of the more incremental type we focus on. A radical innovation is generally a new product. When a radical innovation is introduced into the marketplace, conditions are very fluid; performance tends to be maximized at the expense of cost and the market structure and corporate organization may change rapidly as firms move in or out of the business. Incremental innovations occur in more "mature" industries, and are replacements for products (or processes) already in use. Thus, cost is the crucial area of competition, and prices and market structure are relatively stable. The fundamental features of the process, as discussed below, are not different; what is different is the rate of change of technology, the market structure, and product costs.

3.1 THE NATURE OF THE INVESTMENT PROCESS

The process of technological change in the private sector can be divided into four somewhat arbitrary phases: invention, development, introduction, and diffusion. Because these activities cost money, and offer no immediate return, the expenditures involved are investments, and each of the steps is usefully thought of as involving an investment choice. That is, at each step

---

[1] The differences between the two types of innovations have been made clear in recent work by Abernathy, Utterback, and co-workers, in The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry, W.J. Abernathy (Harvard University Graduate School of Business, Boston, Massachusetts, April, 1976), and "Technology, Productivity, and Process Change", W.J. Abernathy and P.L. Townsend, Technological Forecasting and Social Change, August, 1975.

the firm can be thought of as acquiring a new asset, where that asset is expected to yield a favorable return itself, or to open the way to some subsequent investment that will yield a profit.

To see the differences among these investment choices, it is useful to look at each in a little more detail.[1] Invention refers to the generation of an idea and, usually, includes some initial laboratory-scale demonstration of technical feasibility. Basic research, which is associated with the invention stage, is really a form of investment in the production of new knowledge. This knowledge may not be associated directly with any current product or process, as when investments are made in the hope that some useful invention will result.

Development is the set of activities which takes a concept which has been demonstrated in only a primitive form, and bring it to a condition where the technological uncertainties are nearly eliminated. Other uncertainties--principally concerned with the market response and government reaction--may remain. The development stage generally involves a substantial investment relative to that of invention. The new concept must be tested extensively, and alternative designs must be evaluated until the concept is embodied in an actual model that can function effectively in the working environment. This stage usually involves a search for the most desirable combination of inputs, performance attributes, and cost structure. Large expenditures may be involved in the extensive engineering, construction of models and prototypes, and

---

[1] A similar delineation of the process of technological change as used in "Federal Support for the Development of Alternative Automotive Power Systems: The General Issue and the Stirling, Diesel, and Electric Cases", L.H. Linden, et al, M.I.T. Energy Laboratory Working Paper No. MIT-EL 76-001WP, March, 1976. We have explicitly sought to bring together both the stages by which new technology is developed and the stages in the "product life cycle".

testing. For such expenditure to be "successful" it must result in a product which management expects to make and sell at a profit.

Introduction into the market includes procurement and set-up of initial production facilities and establishment of all the other activities necessary to generate, support, and subsequently exploit the hoped-for market. This may include a marketing program (advertising, demonstrations, etc.), establishment of distribution channels, formation of a widespread maintenance organization, etc. These activities may be very expensive due to the required investment in plant and equipment. The introduction stage produces knowledge of the market's response to the new product; it also should elicit the government's response as well, if regulatory or other interventions have been in doubt. Very often the investment in the introduction stage is not expected to be profitable in and of itself. Accounting losses may be taken at this stage in anticipation of gains in the operation of subsequent generations of production facilities.[1]

Thus a successful introduction is the prelude to the diffusion stage, when usage becomes widespread. The early part of this stage often involves the spread of production of the innovative product to imitators or licensees of the first firm, as well as a build-up of production capacity by the innovating firm itself. If the new product is bought by purchasers in increasing numbers, and its actual use becomes widespread, then new technology is becoming embodied in current technique. If the innovation is a substitute for an

---

[1]This occurred, for example, in the initial sales of nuclear reactors for electric power generation. While the losses actually sustained by Westinghouse and General Electric may have been greater than anticipated, it is clear that losses were expected--see "The Economics of Nuclear Power," I.C. Bupp, et al, Technology Review, February, 1975.

existing technology in use, the stock of capital embodying the older technology is retired during this process.

What makes this process go? In our society, it is the pursuit of economic gain. The decision by a firm to make the investment required in any of the stages of the innovation process is based on the expectation that the returns--the incremental incoming cash flows, appropriately discounted--will be greater than the expenditures.

At the most basic level, there is no conceptual difference between the investment decisions made at each stage. The task of management is to allocate the firm's capital to the most valuable investment opportunities. That means finding real or intangible assets that are worth more than they cost--assets with positive net present value--and the essential key to the decision is the "valuation" of the asset to be acquired. But the earlier the firm stands in the innovation process, the harder it is to specify operational procedures for evaluation. At the last stage, diffusion, most firms use standard financial techniques, such as discounted cash flow analysis. At the first stage, decision making is based almost wholly on judgment and intuition.

The problem is not simply the greater uncertainty faced at earlier stages. There are important differences in the <u>kinds</u> of things a firm is purchasing when it makes its choice. Once again, if we think of the investment decision in terms of assets that are acquired by the firm, one important distinction becomes evident. Assets required at earlier stages have value not primarily because they are expected to produce net incremental cash flows in and of themselves, but because they open up the opportunity to take the next step with the technology. In effect, investment in an early stage is like the purchase of an <u>option</u> to invest in later stages.

The complexity of the process, and the difference in the valuation task at each step, can be seen by reviewing each stage in turn. The payoff to investment at the final stage (diffusion) results from acquisition of a set of assets which generates a stream of positive expected cash flows. The valuation process boils down to discounting the stream at a rate appropriate to its risk. The higher the risk, the higher the opportunity cost of capital for the asset under consideration, and the higher the appropriate discount rate.

Many uncertainties are resolved by the time the diffusion stage is reached. A firm can look forward to "normal" business risks--which may be substantial in absolute terms, but still small compared to risks at earlier stages. Once the introduction stage is past, the firm has experience in manufacturing and costs are relatively predictable. Buyers have observed and evaluated the new product, so demands for it can be reasonably well forecasted. To the extent that regulatory, institutional, or legal difficulties are relevant, they often have been flushed out and defined, if not resolved.

The risks at the introduction stage are greater. Technological unknowns have been largely resolved, since the development stage has been completed. However, actual production costs at commercial scale remain somewhat uncertain--simply because production at that scale has never taken place before. Knowledge about demand may not be so well in hand, because the product has not yet faced the test of the market. Market surveys and other data collection and analysis techniques can be used, but they give only partial relief. Uncertainty about government regulations must be faced during introduction. Environmental or other regulatory or political problems may not be resolved until the early plants are built and the product actually used.

A decision maker might attempt to take account of the higher risks of the introduction stage by discounting projected cash flows at an appropriately higher rate, arriving at a discounted present value by the usual procedure. But such a procedure, crudely applied, misses an important aspect of the problem. The most valuable payoff to the introduction stage is the option to make a future, diffusion-stage investment. If the introduction stage is a success, then the diffusion-stage investment will have a positive net present value.

A similar argument can be made if the decision is yet one step further back in the process. The chief motive for making a development-stage investment is to acquire an option to proceed with introduction. If development stage uncertainties are favorably resolved, the firm proceeds to the next stage--it exercises its option. If they are not favorably resolved, the firm still has the option to continue, but the option is not exercised.

Thus, investing in development can be thought of as acquiring an option to purchase an option. Investment in basic research can be thought of as acquiring an option to purchase an option to purchase an option! The early stage investments are the first of many possible follow-on investments. Each is a part of a complex, sequential process.

3.2 THE INTRODUCTION STAGE AND "COMMERCIALIZATION"

In terms of this simple four-way breakdown of the process of technological change, it is the introduction stage that is the target of federal programs and proposals in the area of "commercialization". ERDA and other federal agencies also are engaged in R&D that is more reasonably classified with the invention and development stages, but those activities are not the main focus of this study. Here the concern is with plants that are at or near commercial scale, or with the marketing introduction of new production under something approximating commercial conditions.

As the previous section stresses, the introduction stage is part of a long process of investments, and is intimately tied to the prospects of profitable diffusion. Now, given that our attention is focused on introduction and its link to diffusion, there are several other aspects of the commercialization process that deserve mention. First is market differentiation. The simple definition given at the beginning of this section might be taken to imply that a technology is either "commercial", or it is not. But this would be a misleading simplification of reality: Today heat pumps are commercial in the south but not in the rest of the United States; electric vehicles are commercial for the delivery of milk in the United Kingdom but not as passenger cars anywhere; even synthetic crude oil has been and is being produced in other countries. This is the usual course of events--technologies are almost always used first in markets for which they are most suited. Some energy technologies which now appear to have reasonable chances of being commercialized within the next decade or two will most likely be utilized first in such limited markets: Automotive gas turbines will likely see first applications in long-haul trucks rather than passenger cars; solar heating and cooling will appear in the southwest United States rather than the northeast, etc.

Commercial adoption therefore is not a simple transition from non-use to use; it is part of the dynamic and complex process whereby a new concept may penetrate some markets but not others, or where the penetration may move at very different rates depending on prices, weather, market structure, etc. The transition often is not a smooth one, as some initial ventures fail and the key technical attributes are sorted out.

Secondly, the energy technologies themselves may present very different challenges at the introduction stage, and the role played by the first plants may be very different. To take a simple but dramatic example, compare the introduction of shale oil with that of solar household hot water heaters. With the introduction of small-scale solar devices, a firm must proceed with an effort large enough to gain reasonable economies of scale, and to sustain a viable marketing and distribution strategy. But the investment need not be large in relation to the size of the investing firm or the supporting capital markets. If the introduction is successful, the firm can anticipate significant economies of scale and "learning" in the diffusion stage.

Shale plants are different. Not only is the potential cost much greater for each plant, both in absolute terms and in relation to operating cost, but the expected pattern of costs in the diffusion step is very different. The firm cannot anticipate such "learning" and scale effects with the second, third, and fourth plants as the solar manufacturer can with a successful market penetration. If the nuclear power industry is any precedent, subsequent synfuels units will each involve a new design, and something of a new start so far as "learning" is concerned. Moreover, the investment is large. If set up as an independent corporation today, a single 50,000 barrel per day shale oil facility would be number 110 of the "Fortune 500" when ranked by assets.

A third consideration is the set of complex adjustments that may be involved in integrating a new technology into a highly developed and interrelated production and marketing system, where the key firms have taken on a structure and personality compatible with the <u>previous</u> product mix. For example, shale oil would involve a whole new "business", even for a major oil company with considerable experience in refining and petrochemicals; the investment structure would be drastically revised; the financial and management structures would have to change; corporate profits would be made in different parts of the business than before; tax and regulatory issues would arise. It is hard to do justice to the number of considerations that would prove relevant for any particular corporation faced with such a decision, but Table 3.1 shows a suggested list of the types of questions that would have to be dealt with in the corporate planning and decision process.

An additional dimension of complexity is added when the new industry is destined to emerge under the bright lights of public scrutiny, for one of the competitive advantages and bases for profit normally inherent in an emerging industry is its "mystique". When this "mystique" is removed through the externally stimulated dispersion of know-how and the constant need for justification to the public, the effect on the private sector's perceptions of risks and rewards in entering the new industry are unclear, and thus the resulting effects on the private sector's willingness to enter the new industry are unclear as well.

3.3 THE MARKET PROCESS AND SOCIAL GOALS

The previous section stress the complexity of the process of "commercialization" of new technologies under our mixed market system. But the fact of complexity does not mean that the system does not work well. Quite the contrary. The United States stands at a point of world leadership across many if not most fields of industrial technology, and this is the case only because the system does work, and very efficiently.

Table 3.1

FACTORS A LARGE COMPANY WOULD CONSIDER
BEFORE ENTERING INTO A NEW BUSINESS

Internal to the new business:

Are the margins high or low?
Is change in technology fast or slow?
Labor or capital intensive?
Unit of sale large or small?
Life cycle long or short?
Where now on life cycle?
Where is profit leverage?
How does it relate to our resource base?
What are barriers to entry?
What is the growth rate?
Where would we and competitors be on the learning curve?

Financing:

Simple or complex?
Joint ventures likely or not?
What is time distribution of cash outlay and payback?
What is cost of abort?

External to new business:

Government intervention high or low?
Competition large or small?
--what are our competitive strengths and weaknesses?

Relatedness to existing business:

Is it an extension or a diversification?
Is it significant in size?
--relative to our firm?
--relative to the industry?
How does it affect the rest of our businesses?
--how is it synergistic?
Subject to same risks, or different ones?
What parts of existing business _must_ we protect?
--does this protect them, or add new areas that must be protected?
How would we be different with it?
--without it?
What are alternatives?

Timing:

Why now?
--now or never?
--should we lead or follow?
How would we be different if not now?
--wait, and buy in later?

There are specific problem areas, however, where the system does not necessarily serve the larger interests of society. Firms are led to employ technologies that are not in the larger national interest, as in the case of uncontrolled industrial pollution. Or there may be technologies which are desirable from a social viewpoint, but which the private sector has no incentive to develop and implement. Since we entrust much economic decision making to the market--and in general we hold to a theory of economics that says that such market decisions will be socially desirable[1]--such undesirable outcomes are often referred to as "failures" in the workings of the market system or "market failures".

Presumably, if we felt that things were going well in the area of energy and technology, we would continue to leave the issue largely to the private sector, as we have for two hundred years.[2] ERDA would not be as large or as diverse in its scope as it now is.

Given this history, and the current private-public split in the energy sector, a useful way to organize inquiries into the federal policy in the area of energy technology is to ask where the instances of "failure" are, and what it takes to correct them. The question addressed in this study is of this type, but is more narrowly defined. Here our concern is with the failures that are related to the introduction stage of important new energy technologies and with the identification of those failures that may be corrected

---

[1] Here we do not address the issues surrounding government involvement in the earlier stages of R,D&D. For a discussion of this topic, see Energy Research and Development, J. Herbert Holloman, et al., and Michael Grenon (Ballinger Publishing Co., Cambridge, Massachusetts, 1975).

[2] There are a few notable exceptions, such as government R&D in the nuclear industry. Of course, it also is true that government activities outside the R&D area have had a tremendous effect on the composition of the energy sector--e.g., the interstate highway system and the tax code.

by government subsidies of commercial demonstrations, or other efforts to facilitate "commercialization".

3.3.1 Energy Prices

As suggested in the simple definition of commercial feasibility at the beginning of this section, a key determinant of the viability of any new energy technology is the price of energy itself, and the expectations about this price in the future. If the energy price fails to reflect the social value of a barrel of oil supplied or a BTU saved, then a fundamental flaw is introduced into the normal process of decision making about private investments in new energy technologies. This is not a "failure" that can be directly corrected by government efforts at commercial demonstration or related activities, and so is outside our direct concern here. However, the energy pricing question is critical to the whole process of technological change, most especially at the stages of introduction and diffusion. Expected energy prices are, as a result, especially important to the planning and evaluation of government intervention at the introduction stage.

The situation is both complicated and uncertain, as a brief look at current price-setting processes reveals. Energy prices certainly are not determined by simple considerations of domestic supply and demand. They are the result of a complex set of controls by the U.S. government and foreign nations, as well as the usual market processes. We will discuss only oil and gas, our two "scarcest" domestic resources.

Oil Prices. World petroleum prices are set by a cartel, the members of the Organization of Petroleum Exporting Countries, OPEC. The current Persian Gulf price is $11.50 for the standard or "marker" crude; in 1969-70 the actual market value was around $1.30, or in 1976 prices, around $1.90. At those prices, and higher ones in producing regions closer to market, there was chronic potential excess capacity. Thus the cartel price is today about six times (inflation-adjusted) a price which was above the competitive level before the cartel became effective. While in the global perspective such a price is very inefficient, this country, and consuming countries generally, can only treat the cartel price as an external fact, and seek the least expensive adaptation to it.

It is widely believed that the current oversupply of oil will gradually be superseded over the next several decades by true scarcity, as existing reserves are replaced only at a very much higher real cost. Thus, even if the cartel holds, the price will then be no lower, in real terms, than today. The cartel's profit-maximizing price may be higher or lower than the current level and thus may be changed. The cartel may run into serious trouble, and the price may fall substantially. Or the cartel may attempt to cut prices in selected markets to destroy competitors. Finally, the cartel may take actions which are not motivated by economics at all, but rather by politics; in this sense it may not play the usual rules of the game. These possibilities make investment more risky (than at the same price without the cartel), which means that the price necessary to draw in investment must be high enough to provide a return above the one suitable for "normal" commercial risk. Thus, for example, rational investors would not support a synthetic crude oil operation whose product cost equaled the cartel price, unless that cost included a "high" rate of return on the investment.

Until 1971, the United States limited crude oil imports through a quota system. (The system remained in existence but without effect for two more years.) This maintained prices in the United States above world levels. The import quota augmented a highly complex system of regulation of domestic oil production. Partly it operated through the tax system. Depletion allowances lowered the tax burden on the domestic production of oil and gas (along with other minerals), thereby increasing the attractiveness of before-tax profits upstream of the wellhead and drawing in capital from otherwise competitive investment. The most important producing states, notably Texas and Louisiana, controlled the total petroleum production, but on a per-well basis, thus artifically stimulating drilling by individual lease-owners. This resulted in higher investments by the industry than would otherwise have occurred.

This system has largely disappeared, succeeded by a new set of contradictory features. The value to the American economy of a barrel of oil produced at home is (at least) the value of domestic resources which must be shaped into goods and services to be transferred abroad to pay the foreign government-owner. This is the price of international oil delivered to the United States, somewhat over \$13 at the present time. But petroleum prices in the United States only indirectly reflect this social value; rather they are presently set by the complex system of petroleum price controls. Domestic producers face prices of \$5.25 for "old oil" and \$11.33 for "new oil". Oil in these classes will not be produced if it costs the operator more than these prices, even though they are substantially below the real social value of the oil. Buyers, on the other hand, face a price of \$9.50, which is the weighted average of these domestic supplies and imports. They then have inadequate incentives to conserve, as the expense avoided in not consuming a barrel of oil is less than its social value. These prices have been established by the federal government, not for economic efficiency but in order to prevent a competitive disadvantage for refiners who do not own crude oil which can still be cheaply produced; and to prevent windfall profits to the owners of this crude. Obviously, prices designed to regulate competition, and do justice, cannot be expected to give the signal of value emitted under simple competitive conditions.

National Security Premium. The social value of domestic oil is not determined solely by the international price: There is also the issue of import "dependence". It hardly needs to be stated that the United States is increasingly dependent on a small group of foreign nations for our petroleum imports. This group is well organized and may attempt to influence our foreign policy by actual or implicit blackmail. This is a social cost which would not be reflected in private places even if those prices were not controlled by the government. It may be described as a "national security premium", associated with imported oil only. Since a barrel of oil domestically produced or conserved effectively translates into avoidance of an imported barrel, it is the international price plus the national security premium which is the effective social value of domestic supplies. However, while this concept seems a reasonable one, it leaves us with, at minimum, a substantial measurement problem: How much is it worth to us to avoid importing a barrel of oil? We defer discussion of this question to Section 5; for now, we assume that the national security premium is large enough to be a contributing factor in the ensuing discussion. Given the national emphasis on reducing imports of petroleum, this seems a safe assumption.

Natural Gas Prices. The regulation of the price of natural gas is a longer-term and more complex form of the same problems. In the producing areas of the southwest, natural gas is still available on intrastate shipments, at a price which appears to have become approximately equal to that of "new" crude oil in energy-equivalent terms, and to residual oil, but higher than Rocky Mountain coal. Electric utilities appear to be following this signal, and gas is being phased out. The effective demand for new gas is limited to the intrastate market. For many power plants, especially when located close to areas of gas production which have no alternative pipeline connections, the price of gas is still below that of competing fuels, and there is an incentive to keep burning it.

Outside the producing states, the price of natural gas is only a small fraction of the equivalent price of oil. The national ceiling is 52 cents per million BTU,[1] equating to about $3.12 per barrel of oil, or 7 1/2 cents per gallon. At such prices, there is an enormous unsatisfied demand for natural gas, the well-known "shortage". Strenuous efforts are being made to import liquid natural gas (LNG) from OPEC members, and to manufacture synthetic natural gas (SNG) from coal. Expected costs in the range of $20 to $30 per barrel of oil-equivalent will apparently not attract private investment into SNG production. Since the real resource costs of producing and shipping LNG are considerably lower than SNG costs, the OPEC governments supplying LNG have considerable leeway in their pricing decisions and their policies will determine LNG availability. It is not clear whether gas consumers are prepared to take large amounts at these prices, or whether in time they will substitute away by changing their heating apparatus. In any case, consumers will not be confronted with these high prices for a long time, for the new sources apparently will be "rolled in" with the much lower prices of existing interstate natural gas.

Thus producers and consumers of gas are offered multiple conflicting price signals. Synthetic gas would cost eight times current natural gas

---

[1]There is a proposed increase now in the courts.

prices to consumers. A gas consumer in Texas is paying, at present, about four times the price charged to the interstate consumer for his gradually dwindling flow for new gas; the new interstate consumer faces an infinitely high price--it is not to be had at any price. Eventually the low price and the infinitely high price will come together at a price which is very high by today's standards, and higher than the price which consumers considered when they installed their equipment.

Were there no price regulation, it is not clear that the demand for LNG and SNG, for base loads, would exceed zero. Some 65 percent of natural gas is in industrial uses (chiefly electrical power) where it can be replaced by residual fuel oil and coal. If gas is to be deregulated over the next ten years, then investment in LNG and SNG, projects which add to gas supply by 1985, may prove completely wasteful. The presently perceived "need" for large-scale supplies of gas will turn out to be the misinformation generated by price regulation.

Impact. The impact of the pricing regulations on investments in technological change depends on the particular circumstances involved. Any conservation technology, for example, is at a strong disadvantage due to low gas and oil prices in domestic markets. The amount a buyer will pay for a piece of energy-conserving equipment is directly related to the price of the energy conserved. If the energy is a petroleum product, for example, then that price is now being held well below the actual marginal cost of the energy to the nation--which is the price set by the OPEC cartel. A barrel of oil saved is valued by the consumer at the domestic price, but the savings to the nation is the cartel price; the difference is a savings accrued by the nation as a whole but not the individual conserver. Clearly, then, any activity which involves oil or gas conservation is privately undervalued. In particular, the investments in the development and introduction of new energy-conserving technologies will be less extensive than they otherwise would be.

Energy supply technologies will be affected to an equal or lesser extent. Solar heating and cooling of homes, for example, may displace consumption of refined petroleum products. In this case the impact of price controls is similar to that on conservation. On the other hand, new sources of synthetic crude oil, such as oil from oil shale, presently appear to cost more than imported crude, so it is hard to conceive that an attempt would be made to control the sales price.

The distortions caused by inappropriate energy prices apply across-the-board to all stages of the process of technical change. Where the value of the ultimate product of technological change is decreased by undervaluation of domestic energy, there is a lowering of the expected returns to an investment in any stage in the process. Naturally, the importance of the effect is very different at different stages. At the invention stage it is the expectation of prices several decades in the future that is important, for that is when a new innovation would reach the diffusion stage. Needless to say, such prices are very uncertain; therefore, they are likely to enter into the investment calculation only in a very crude manner. The fact that the attributes of the innovation (after any development and introduction stage) are very uncertain as well only serves to further reduce the relative importance of prices in decisions at the invention stage.

The impact of energy prices is very different in the diffusion stage. There the technology is well defined, and the innovation will be adopted to the extent that is profitable to do so. Inappropriate prices have an increasingly important effect as a technical option advances from invention, through development and introduction, into diffusion.

Thus, domestic price controls create a situation where subsidies to conservation efforts may be socially profitable. However, government intervention in support of the commercialization activities--without long-term subsidies--would be limited in its impact, for the demand for such technologies, once introduced, would remain too low. Commercialization would fail, as diffusion would not occur. In such circumstances price controls and expectations of future controls are a dominant influence on the rate and extent of technological change, and a principal force in preventing adequate private performance.

3.3.2 Failures in the Process of Technological Change

Clearly, the current process of price determination, and likely developments in the future, are an important boundary condition for all of ERDA's planning. Much of this process is poorly understood, particularly where it is heavily influenced by government policies and the associated domestic and international politics. A high priority should go to efforts to understand and analyze it. So far as U.S. domestic policy is concerned, almost any measure to clarify the long-term price policy would be helpful, and of course the higher the energy price that is found tolerable, the more rapid the rate of technological change will be, regardless of federal efforts to help.

Whatever happens on the price side, however, there are a number of other problems that may lead to a less-than-desirable level of investment in new technology by private firms. There are several categories into which these "failures" are conventionally gathered, and a survey of each reveals something about the types of activities where government efforts might be most usefully focused.

Inability to Appropriate Technical Results. Usually, when a firm makes an investment, it expects to capture the outputs or returns for itself; it would prefer that the results not go to everybody, for then no competitive advantage has been gained. Technical information is difficult to control, however, and once it gets out any other firm may use it without paying the originator. That is, the results are not "appropriable". In the terms used earlier, a firm carrying out R&D may not be buying an option for itself alone, but for all its competitors as well. The incentive to make such investments is thus dampened, for the firms' returns from the investment are less than the social returns--which include the profits of other firms as well as the benefits consumers realize from less expensive or improved products. This is a market failure in the sense defined above.

Of course, the patent system is designed to remedy this defect, and firms also make efforts to protect proprietary technology which is not patentable. But there remain substantial classes of knowledge which are excluded from the patent system or are not readily held proprietary, or which might contribute in widespread or unforeseeable ways to new products. One such circumstance is basic research. Because of difficulties in appropriating the benefits of a fundamental contribution to knowledge, government subsidies are commonplace. This type of market failure becomes less significant as a technology progresses to later stages of development. Technical knowledge becomes patentable, or more readily held proprietary, as the new knowledge becomes embodied in a product.

One technique which can be used to mitigate the non-appropriability problem is the use of industry consortia to support development programs. The firms which stand to gain from a given class of advances can join together to finance them. Then the individual firm's proportional investment can be made to approximate its proportional ability to profit from the advance, and the group as a whole can capture the bulk of the benefits. The Electric Power Research Institute, for example, is supported by contributions from the nation's electric utilities; it supports R&D on electric power generation technology. However, for anti-trust or institutional reasons, it is not always possible to organize the appropriate group.

To what extent does this phenomenon apply in the introduction stage of the process of technological change? There are several types of information involved. First, technological information will be developed as the product embodying the new technology is produced and used. This information is generally reflected in decreased costs of subsequent plants. For example, it is estimated that the first plant to produce a new type of automotive powerplant would cost several times as much as subsequent plants of the same capacity.[1] The major issue, then, is the extent to which cost reductions are appropriable by the firm introducing new technology. It is widely presumed that benefits of this sort in fact are substantially appropriable, in contrast to the extreme case of new fundamental knowledge. One argument is that knowledge is embodied in the collective experience of the engineers and managers of the firm, and so cannot be readily learned by outside observers. Engineers and managers can be lured from firm to firm, but rarely *en masse*.

Determination of the importance of this "failure" is not a simple matter in any particular case, and the conditions vary greatly across industries. Therefore, continuing efforts to understand this problem are very important

---

[1] "Should We Have a New Engine? An Automobile Power Systems Evaluation. Volume II, Technical Reports," (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, August, 1975).

to ERDA's efforts--both to identify which situations are truly blocked for this reason, and to guide the selection of the proper instruments for subsidy.

Regulatory and Political Risk. It may be that the proprietary technical and cost information developed at the introduction stage indicate a technology sufficiently attractive to induce socially desirable outlays, but regulatory and other institutional problems intervene. Important institutional, regulatory, and political issues posed by the new technology may be resolved only by substantial production and use. This is true for synthetic fuels, for example. Information about environmental effects of full-scale plants may be inferred from pilot plants, for example, but the issue of what effluent levels are acceptable is difficult to resolve until production is attempted on a commercial scale. This is a special kind of distortion of private decision making: Investment may be artificially discouraged because society has not gotten around to specifying the rules under which the new technology will operate.

For example, the diesel engine has special emissions problems (e.g., particulates) that may create problems if the engine is ever widely used in private automobiles. As yet the emission standards to be applied to diesel emissions have not been determined by federal regulatory authorities, and so long as this uncertainty remains it is not in the interest of any manufacturer to spend substantial sums of money on the introduction of the diesel engine. Ultimate regulatory constraints may or may not be set at a level that allows the diesel to function as a passenger car engine. But in the meantime, uncertainty about regulation magnifies the risks of development. Unfortunately, it is unlikely that the Environmental Protection Agency will start the necessary impact studies and begin to formulate procedures for setting particulate emission standards until diesel use becomes widespread. Similar regulatory barriers, or potential ones, will be faced, with greater or lesser impact, by any important new energy technology.

This circumstance suggests that a well-designed government intervention may be very useful. If socially valuable new technologies are blocked by the "regulatory risks", then an off-setting subsidy may be in order. The subsidy would not only encourage use of the technology, which is good in itself, but also lead to a resolution of the regulatory risk and open the way to further, unsubsidized investment in the technology by private firms. Effectively, the subsidy would cover the private costs of developing the necessary case law, regulatory rulings, etc. Careful study of the nature of the regulatory problem should, once again, offer guidance as to what kind of subsidy will most effectively resolve the issue.

There is a cautionary note that needs to be sounded here. We are speaking of intervention by the government to resolve differences created by regulatory procedures, administrative agencies, and court rulings which, speaking loosely, comprise the "government". Therefore, there are several issues that naturally arise in connection with a federal subsidy program which is heavily influenced by these considerations:

1. The barriers may be political, in the sense that there is a latent, unresolved conflict between two or more parts of society. What are the consequences of attempting to force an early resolution of the conflict? What would it take to resolve it?

2. Are the risks truly "artificial" ones, reflecting no more than the tendency of persons or organizations to avoid the effort and controversy required to resolve the issue? Or does the reluctance to decide reflect an actual lack of knowledge about the effects of full-scale use of the new technology? In the former case, all that is needed is for regulatory or other governmental agencies to give a clear statement of the rules of the game. (Of course, this may be difficult to do in a society where political and regulatory authority is decentralized--more on this below.) In the latter case, the building of commercial-scale facilities may or may not be the cheapest way to gather the needed information. (This point is also expanded below.)

Market Structure. Issues of market structure may be important in the process of technological change. Monopoly power in any market generally is associated with excessively high prices. Such prices would certainly have an across-the-board impact on investments in technological change. We have discussed the energy prices above. Any other market would require a detailed analysis of its own.

Potentially more important, and less well understood, is the impact of market structure directly on the propensity to innovate. Simply put, large firms may be needed to support large research and development establishments and to risk the investments needed to introduce new technologies. On the other hand, firms with monopoly power would seem to be under less competitive pressure to hold costs down and generate innovative products. Moreover, under competition the inducement to innovate is greater because the innovator makes all the gains while his competition bears the losses. A monopolist must do a private cost-benefit calculation, and may turn away innovations which would have been profitable under competition.

For example, one situation where there is debate about the influence of concentration on innovation is the automotive industry. The supply of automobiles to the American market is dominated by the "Big Three", with a fringe consisting of one "independent" and a number of importers. In such a circumstance there are good reasons to suspect that the full play of competitive forces is not brought to bear. On the other hand, the existence of such huge industrial complexes gives opportunities for innovation that might not exist were the industry made up of smaller units. There is no consensus on whether more or less innovation takes place under current market structure or some alternative. Government support for commercialization of new automotive engines must deal with the industry structure as it is, at least making some effort to ensure that such support does not increase the degree of concentration.

Risk and Financial Markets. It is often argued that investment in new energy-related technologies is blocked by lack of financing. The investments at the introduction stage are so large, and so risky, it is argued, that private investors are unwilling to advance the necessary capital.

Even if true, this may or may not be a "market failure". When an investment banker states, for example, that large-scale synthetic gas plants "can't be financed", he may simply mean that the expected profitability of investment in such a plant is not high enough to compensate for the risks that would have to be borne. It is irrational for an investor to commit capital to the high risk use if the anticipated return is not correspondingly large. Society as well should demand a high expected return on capital the higher the associated risks.

A market failure occurs when the private decision maker has a degree of risk aversion different from that appropriate to society at large. A common argument is that private investors are too risk averse. It is held that the government is capable of spreading the risk of a particular technological experiment over a very large pool of alternative activities, whereas a private corporation may be limited in its ability to diversify the risk of large investment. Thus a firm would not undertake such an investment, even if its estimate of the expected value of the investment is the same as that of the government. In such a circumstance there is under-investment, from society's viewpoint, in risky technologies.

On the other hand, the U.S. has a highly elaborated and efficient set of capital markets, and these offer extensive opportunities for spreading risks.

The combination of markets for loan funds and the various stock markets for equity capital--supplemented by various forms of joint corporate ventures--can serve to diversify risks very widely over the community of stock and bond holders.[1] These markets appear to serve well in supporting potentially profitable investment--including very large and risky ones--in energy and in other sectors of the economy. Thus there is no a priori reason to believe that capital markets are demanding an excessive risk premium for investments in new energy-related technologies.

It is true that some ventures with new technology are large from the point of view of a single firm. If the goals of management include objectives other than increasing stockholders' equity, then this "exposure" may be a significant factor in the investment decision. This is likely to be the case for a new venture by one of the many large American corporations which finance their investments almost entirely with internally generated cash, making such investments less sensitive to evaluation by the capital markets. But in general the problem of corporate timidity in the face of risk does not seem a crucial one; it is unlikely that it could long block investment in new technologies, providing that they offered profitability sufficient to attract debt (or perhaps equity) funds from capital markets. Not all corporations or managers are risk averse: we observe corporations, for example, investing hundreds of millions to acquire off-shore drilling rights, even though there

---

[1] Diversification cannot eliminate all the risks of investing in new energy-related technologies. The revenues and costs of a synthetic gas plant depend on inflation, the rate of growth of the U.S. economy, the OPEC oil price, and many other factors that affect, in varying degrees, the aggregate value and profitability of the economy's real assets. These risks cannot be diversified away by the individual investor or by society as a whole. In principle, only these systematic or non-diversifiable risks are relevant in assessing the present value of an investment opportunity.

is a significance chance (proven by experience) of getting nothing at all.

There are two mechanisms which management can use to mitigate the risks to the corporation. Joint ventures are widely used--for example, the major efforts now underway to commercialize oil shale are mostly combinations of several firms. The other approach is to organize the new venture as a separate corporation. This provides the protection of limited liability for corporate, institutional, or individual owners. Financing for such a venture should be readily forthcoming if anticipated profitability is high enough to compensate for the risks involved.

3.3.3 Prices and Other Problems: Summary

Here we have viewed the process of technological change as a series of investments undertaken principally by the private sector. Government efforts to spur the commercialization of new technologies constitute an intervention in only one stage of a long and complex process. In many respects the process itself is not well understood.

Our analysis of the relative social and private incentives to technological change in the energy sector is summarized in Table 3.2 Several features of the table stand out. First, we have only very limited knowledge of some of the key features of the process of technological change and, in particular, the extent to which it occurs effectively without government intervention. Except in the diffusion stage, where the returns to investments can be calculated with reasonable accuracy, it is very difficult to say whether, in any given case, resources are being allocated to the innovative process in anywhere near the socially appropriate amounts. One is left with examining the incentives to technological change, rather than the amount of the investment itself. Further, as indicated in Table 3.2, there are cases where even

Table 3.2

IMPACT OF MARKET FAILURE ON STAGES IN THE PROCESS OF TECHNOLOGICAL CHANGE

Stage in the Process

Source of Market Failure	Invention	Development	Introduction	Diffusion
Oil and Gas Price Controls	Probably Unimportant	Important Where Relevant	Very Important Where Relevant	Crucial Where Relevant
National Security Premium	As Above	As Above but Magnitude Unclear	→	→
Inability to Appropriate Technical Results	Probably Important	Less Important	Usually Considered Unimportant	Unimportant
Regulatory and Political Risks	Unimportant	Less Important	Unclear May Be Important	Unimportant
Market Structure	Unclear Depends on Industry	→	→	→
Risk and Financial Markets	Unclear	→	→	→

the direction of the effects of the incentives are unclear.

Government-supported commercial demonstrations affect only the introduction stage in the process of technological change. A crucial issue, then, is the extent to which there are market failures in that stage only, which might be corrected. We will take this question up at some length in the following section. An examination of Table 3.2 indicates, however, that the non-appropriability of the benefits from the resolution of institutional problems is the only such difficulty. Other problems--energy price problems in particular--may lead to inadequate incentives in the introduction stage. But these difficulties apply to other stages as well, and must be examined in a larger context.

4. GOVERNMENT-SUPPORTED COMMERCIAL DEMONSTRATION: GOALS AND MEANS

In this section we focus on government-supported commercial demonstration programs. First the circumstances under which such programs are likely to be both effective and socially profitable are examined. Next the alternatives to commercial-scale demonstrations are examined. Such programs are bound to be tangled in political and institutional problems; these difficultes are reviewed. Finally, we discuss the specific financial instruments which might be considered in supporting such demonstrations.

4.1 THE ROLE OF GOVERNMENT INTERVENTION

In Section 2 we concluded that ERDA's goal should be to lower the cost of substitutes for oil. This would be the result of R,D&D programs which make new technological possibilities available to the private sector. ERDA must perform this function within an environment which is not under its control: Specifically, energy prices are determined by a combination of foreign governments, higher level policy decisions of the U.S. government, and market forces.

Section 3 examined the process of technological change as it normally occurs in the private sector. Technological change is the result of a series of investments which are made in the expectation of a suitable return. Expected prices are the key parameters, external to the firm, which affect the investment decisions. In the early stages of the process, the relevant prices are those expected several decades in the future. They are therefore very uncertain, and the uncertain technological potentials are the dominant factors in the investment decision. At the introduction stage, however, the relevant prices are crucial to the investment decision. There may be some technological uncertainties remaining at the time of the decision, but they are relatively small; the cost of the new technology is reasonably well known (usually, though not always, within 50 percent or so), and the relation of this expected cost to the expected price is of crucial importance.

Ideally, ERDA and industry should be using the same prices in their evaluations of the commercial potential of new technologies. They are both estimating the same quantities--the market prices of the product and the key inputs in its production. These prices may be heavily influenced by future government action, and may show the effects of significant market failures; at any rate they are out of the control of both ERDA and industry. Thus, unless there are significant differences in technical judgment between ERDA and industry, their evaluations of the long-run commercial potential of a technology, estimated at the point of the introduction decision, should be essentially the same.

In most cases the long-run commercial potential of a new technology, when evaluated prior to the introduction decision, will be independent of possible federal interventions in the introduction stage. In most cases, the costs of the introduction stage (which often are not recovered <u>during</u> that stage) are a small fraction of the total cost of the product <u>after</u> introduction.[1] If, when examined at the end of its development, a technology appears to be commercial in the long run, it usually will be introduced and "commercialized" by the

[1]This is the usual case; consider synthetic fuels or a new automotive engine for example. A possible counterexample is the SST, depending on how one defines the stages in that case (see Appendix D).

private sector. In most cases, ERDA commercial demonstration programs therefore simply do not have very much leverage. They may be useful, but they are not often likely to be decisive in determining the fate of a new technology.

Thus, ERDA's commercial demonstration programs can be viewed somewhat crudely as subsidies or offsets to the "introduction stage"--i.e., the excess of cost over production revenues during the introduction stage. It may be viewed as an "industry-front-end" cost, analogous to the usual "plant-front-end" costs necessary to get a single plant into operation. After these costs are sunk, the industry operates at some "long-run marginal cost".

Before these costs are sunk (i.e., at the introduction decision) private firms will include them in their evaluations of whether or not to commercialize a new technology. Where the long-run marginal cost plus an appropriate return on the introduction cost is less than or equal to the expected price, industry will proceed. ERDA commercial demonstration programs can reduce the introduction cost, and therefore they may affect a firm's introduction decision. ERDA's ability to influence such decisions with commercial demonstration programs depends on the relative magnitude of the amortized industry-front-end cost and the expected long-run marginal cost.

Under what conditions should ERDA intervene to reduce these costs? The answer to this question hinges on the analysis, in Section 3, of market failure in the process of technological change. There are two important circumstances where private industry may not have sufficient incentive to commercialize a new technology, and where subsidies to the introduction stage can be socially profitable.

The first is the non-appropriability of the technical and institutional information generated at that stage. Because of the complex and dynamic nature of the markets for new products and processes, the importance of this failure is an open issue. However, we assume that a crucial role of government-supported commercialization is to subsidize the acquisition of this information.

The second occurs when energy is underpriced. When the expected social value of energy is greater than the expected market price, then subsidies to any of the stages of the process of technological change may be good investments. ERDA's forecast of the social value of energy depends principally on projections of OPEC's pricing policies and the extra social cost of the insecurity of imported oil. The market prices of primary energy resources, on the other hand, depend on the OPEC price and government price controls.

Thus, the second possible driving force for government-supported commercial demonstration programs would not be the correction of a market failure of the "usual" sort. Rather, it is the direct attainment of the social benefits associated with domestic production or conservation of energy which is undervalued at going market prices. In this case the introduction subsidy would go beyond the provision of the non-appropriable technical and institutional information discussed above.

The principal benefits which would accrue to ERDA commercial demonstration programs are independent of which of these considerations is used to justify the program. ERDA should subsidize the introduction costs of a technology up to the point where its private cost at introduction just equals the market price. Then the benefit attributable to the program is the present value of the difference between the social value and market price for all the fuel supplied or saved domestically as a result of the program. (Or, if the program only accelerated the introduction of the technology, it is the benefit of the earlier flows which must be computed.) If the total costs of the program, whether devoted to subsidizing appropriable or non-appropriable developments, are less than this benefit, the program is a socially profitable one.

It would be misleading to close this discussion without reference to an important problem which poses further difficulties of program analysis and design. This is the problem of unintended side effects of government programs. Government subsidies to particular technologies may drive out private efforts that would otherwise take place. Firms may decide that they cannot compete with a heavily subsidized program; or corporate management may find it difficult to justify large demonstration expenditures to their boards and stockholders when they can see that the government is doing the job anyway. Thus, on balance, federal support may lower the total resources devoted to commercializing a new technology.[1] Clearly, the planning of government investments in a new technology should take account of the net effect on the entire market, not just on the firm receiving the subsidy. An automotive industry executive communicated this problem to us with the following "hypothetical" example; while it refers to support of R,D&D it applies to subsidized commercial demonstration as well:

> I wonder if you have considered the following hypothetical situation in which it would appear that perhaps government participation might be counterproductive to competition and private industry investments. Assume two automotive companies are working on a similar technology with the objective that if they are successful, they will obtain a competitive advantage and, therefore, recover their investment with profits. Assume now that a government agency decides that the private effort was not as large as would be warranted by the benefits, and therefore elects to support one of the companies with public funds. The second company might drop its own efforts in that area on the basis that the technology developed with the public funds would be available to them as well as to the company carrying out the work with government

[1] Alternatively, it is possible for a government program to lead to an <u>increase</u> in private funding. Something of the kind apparently occurred in the nuclear program when General Electric proceeded to accept turnkey contracts for reactors while Westinghouse projects were being subsidized.

> support. This response to reduced competition would result in a smaller increase in the total effort on that particular technology than had been intended by the original government action.
>
> I don't have a good feel for the likelihood of a response like this example, but certainly government funding could have a significant effect on normal competitive forces.

A related problem arises when government subsidies seem to be pending. Firms may hold back their own projects in the hope the government will pick up part of the tab. It seems, for example, that this may be happening in the solar heating and cooling market at the present time (see Appendix C). Even within the conceptual layout discussed above, this problem provides a formidable challenge to the present state-of-the-art in the design of government programs.

4.2 ALTERNATIVES TO COMMERCIAL DEMONSTRATION

By subsidizing the construction of commercial-scale plants by private firms, it is hoped that most technical, regulatory, and institutional difficulties associated with plants of that size will be raised, if not resolved. Given that the tactical goal of the program is to address these uncertainties, the choice of plant technologies, locations, etc., would presumably be designed to insure that all the important uncertainties are addressed; the resolution of these uncertainties is a principal component of the introduction cost.

However, as with any investment, alternatives which might accomplish the same goals at lower cost must be considered. In fact, government-supported commercial demonstrations attempt to reduce technical and institutional uncertainties with what might be termed a "brute force" technique. It is not clear that the resolution of the relevant technical and institutional uncertainties requires the actual construction of commercial scale plants.

Consider first the technical uncertainties. A commercial scale plant is one which is of sufficient size that there appears to be no great economies gained by simply making it larger. That is, it is designed to produce the product at a scale that is believed to be that which ultimately will prove to yield the minimum unit cost. In any such plant--be it an automotive engine plant or a coal gasification plant--there generally is some subsection of the relevant process technology which is significantly different at commercial scale than at smaller scale. If this were not true, then there would be no economies of scale to be gained by going to the larger size, and the "commercial scale" would be smaller. The crucial question, then, is whether these limited technical subunits are so different from their smaller counterparts that they are not readily scalable. If they are readily scalable--e.g., a larger pressure vessel--then there are no significant technical uncertainties which require commercial scale construction for their resolution.

There may be cases where the crucial subunit is not readily scalable--for example, if it involves the handling of materials volumes substantially larger than in any previous effort. In this case, then, the alternative to building a full-scale demonstration plant is clear: build a facility only of the crucial subunit, and no larger than that necessary to resolve the relevant technical uncertainties.

The case of the institutional or regulatory uncertainties is different. The most obvious alternative would appear to take direct action to resolve the issue. Consider again, for example, the case of particulate emissions from automotive diesel engines. As discussed in Section 3.3, it appears that action to set an emission standard for particulates from automotive diesel engines will not take place until after, possibly well after, a substantial increase in the number of diesel-powered vehicles on the road. Thus the first American manufacturer to engage in substantial production must face a risk that subsequent firms might not have to face.

However, there might be ways to resolve this uncertainty which do not require the construction of large automotive diesel engine plants. Specifically, the Administrator of the Environmental Protection Agency could be ordered, by the President or by Congress, to establish such a standard. He would have to perform the studies necessary to support the sequence of decisions required under the Clean Air Act for the establishment of automotive emissions standards. Of course the proposal and establishment of a standard would not necessarily resolve the uncertainty in a final manner. Just as the standards for pollutants presently emitted from automotive engines are the subject of continuing debate, so the particulate standard might be. However, the gross magnitude of the standard, and its likely effect on engine design, would hopefully be determined. At a minimum, the debate would have been initiated.

Short of a Congressional or Presidential order, other steps might be taken. For example, ERDA might fund the studies necessary to determine whether or not a substantial fleet of automotive diesels would be likely to cause a significant increase in ambient particulate levels. If not, then it might be presumed that any emission standards would not be likely to be constraining, or that they might not be necessary at all. An opposite determination would also lead to a reduction in uncertainty, though the outcome would be less pleasant for the potential manufacturers.

One can, however, imagine circumstances in which nothing short of a set of plants would do the job. For example, it may be the case that nothing short of a completely credible proposal for the construction of a coal gasification plant would force the resolution of the allocation of rights to Colorado River Basin water. There simply may be no other way to force the relevant actors and institutions to come to grips with the problem. Whether this is the case in any given instance would have to be carefully analyzed. The crucial point is that creatively designed strategies for resolution of specific uncertainties might accomplish the same ends as a commercial demonstration program, without the construction of complete commercial scale plants.

It is not obvious that such alternatives would be less expensive than support of commercial demonstrations in resolving the relevant uncertainties. Consider the simpliest possible case: a technology which would be just economic if the institutional and technical uncertainties were resolved, but would not be economic otherwise. The government invites proposals for the construction of a single plant to the relevant non-appropriable information. The incentive is a cash grant, to be awarded competitively. If there is reasonable competition, the bids would be roughly the cost to the firms of dealing with the uncertainties, i.e., the introduction cost. The firms would expect all other costs to be recovered from sales of the product. Thus, unless it were less expensive for ERDA to attempt to resolve the uncertainties directly rather than for the contracting firm to resolve them, there would be no advantage to the direct procedure. Of course this simplistic model misses much of the complex dynamics of the institutional and technical problems in question, but the lesson is clear.

In summary, in any given instance careful analysis is necessary to determine just what uncertainties are being addressed, and whether a commercial-scale demonstration of an entire production unit is necessary for their resolution.

4.3 POLITICAL, LEGAL, AND INSTITUTIONAL PROBLEMS

Even with a sound analytical basis, the implementation of commercial demonstration programs will face substantial political, legal, and institutional problems. These must be carefully distinguished from those factors which are not associated with the government's program, but rather with the actual technologies that are being demonstrated and the industries which the government is hoping to foster. The latter problems, discussed in Section 3, are likely to be the subject of the program.

4.3.1 Lack of Political Consensus, Division of Government Authority, and Lack of Legitimacy

As already suggested in Section 2, ERDA's commercialization programs, like all other aspects of American energy policy, must be implemented in a political environment that lacks national consensus on both the definition of the energy problems and the preferred mechanisms for dealing with it. As a result, the political base of support for any particular commercialization program will probably be narrow, weak, and perhaps fickle. Success at mobilizing support (and therefore necessary resources) at any particular time will not guarantee continuing support in the future. Even success, as measured in terms of the successful completion of a commercial demonstration plant, could as easily erode as strengthen the political support for the overall program. Changes in social values may lead to a reinterpretation of a particular programmatic success as a social or environmental failure. In the absence of assured political support and the guarantee of independence and resources that flow from it, the organization charged with implementing the commercialization program is in a weak position. There will be ample opportunity to falter in one way or another. The cost of faltering, even in a minor and totally reasonable manner, could well be the legitimacy of the whole program or of the organization itself.

Related to the lack of political consensus on energy issues, including those related to commercialization, is the fragmentation of decision-making authority within the federal government and between the federal, state, and local governments. At the federal level, authority for setting policy and providing funding is split between the Congress and the Executive branches. There is no reason to expect that the energy commercialization programs will escape the sort of jurisdictional and power struggles among Congressional committees and between those two branches of government that regularly delay or prevent action in other energy and non-energy policy areas. Within the Executive branch there will be conflicts among agencies and departments that have overlapping or conflicting responsibility for relevant aspects of energy, economic, or environmental policy. Adversary relationships and differences in perspective may develop between such regulatory bodies as the Federal Power Commission and Environmental Protection Agency, and operating government agencies such as ERDA. Difficulties in organizing the commercialization function are indicated by the ambiguities in the responsibilities of the non-operating offices within ERDA itself: the Office of the Assistant Administrator for Planning, Analysis and Evaluation, the new Office of Commercialization, and the newer Office of Program Integration. Possibly even more important is uncertainty regarding the division of responsibilities between these offices and the program divisions, which are responsible for research, development, and demonstration, but not, apparently, commercial demonstration. The allocation of responsibilities, the coordination of policies and the assurance of cooperation among these various branches, units, and sub-units of government will be a difficult but important task, requiring both continuing attention at all levels of government and adequate appreciation for existing traditions, prerogatives, expectations, and power relationships.

In many instances a concerted policy on the part of the federal government, as difficult as that will be to achieve, will not be sufficient. Regulatory and decision-making authority with respect to land use policy, environmental protection, economic viability and tax burden, health and safety facilities, and access to markets via transportation systems may all depend in part on state and local governments and state regulatory commissions. At this level the divergence of interest may be every bit as broad as at the federal level. A split can be expected, for example, between those who seek the help of outside capital to develop the industrialization of a region or local area and those who wish to avoid the social disruption of a large influx of workers and a major alteration of the traditional economic and social structure. This issue has already been joined in some regions of the western coal country, and in coastal regions near prospective off-shore oil operations.

The multilayering of government responsibility would make construction and operation of first plants difficult enough simply because of the need to satisfy many masters, even if the masters agreed on overall policy. In the likely absence of such agreement, the requirements will be particularly onerous. Still, the requirements might be manageable if only there were some societal mechanism with nearly universal respect and legitimacy for making decisions about new technologies and industries. Unfortunately, in the United States today no such mechanism exists. In part this is because of the fragmentation of authority already discussed, but it also derives from the current lack of respect and legitimacy afforded to government leaders and institutions. This in turn is in large measure the result of ten divisive years of Vietnam and Watergate, and as such is by no means unique to energy policy.

But there are additional factors at work in the energy area. For one thing, as with other public policies involving technology, the lack of an authentic and recognized source of technological knowledge often leads to a lengthy and frequently bitter adversarial process.[1] Also, energy policy cuts across, involves, and influences more otherwise largely independent policy areas, and more divergent interests and more ideological perspectives, than most other major contemporary issues of government policy.

There are several results of this absence of a national decision-making process with political legitimacy. Not only does decision making require extended periods of time and frequently involves repeated legal proceedings, but it also is rarely conclusive. Losers rarely accept a decision against them as legitimate and decisive, although repugnant, and instead frequently pursue the matter from one forum and procedure to another. As a consequence, there is a trade-off between expediting programs and providing a wider access of interested parties to the decision-making process.

While these issues of fragmented governmental authority and lack of legitimacy in decision making have an impact far broader than ERDA's commercialization activities, they are highly relevant to these programs. They raise questions about the structure of the political process involved in reaching decisions in this area, about the degree and manner in which various interest groups can be given access to that process, and about the interrelationships and coordination among various governmental entities.

---

[1] The case of the supersonic transport, where technological questions interacted with legal, political, and economic ones in a continuing and extended controversy in many forums, illustrates the possibilities (see Appendix D).

4.3.2 Instititionalization

The creation of ERDA resolved one major issue of institutionalizing the energy technology programs: the creation of a single government agency with primary responsibility for energy-related R,D&D. ERDA's responsibility for commercial demonstration programs has not been so well finalized--there remain ambiguities in the relationship between ERDA and the Federal Energy Administration, and the proposed Energy Independence Authority clouds the horizon as well. Furthermore, both within ERDA and between ERDA and industry, the divisions of responsibility and authority are not yet clearly defined. The degree of public ownership of and control over facilities built as part of the commercialization program, and the legal and organizational structure of owning and managing entities, have not yet been decided. In this circumstance the following dilemma is common: There is a need to give operating control to those with the greatest experience and to simulate market conditions as closely as possible. But a concern not to "give away" taxpayers' money with insufficient controls may lead to avoidance of market forces in favor of more government management and control, and pollution of the data on real operating conditions and costs.

As the commercialization programs grow in size and expenditure, considerable institutional momentum and bureaucratic advocacy will be generated. ERDA officials, Congressional backers, industrial firms, and benefitting regions will all acquire career or other vested interest in the programs' continued existence, strength, and growth. It will be difficult simultaneously to maintain effective control, program flexibility, and the ability to reduce government involvement when industry is able to take over on its own or when the initial justifications for government intervention have disappeared.

One example of this type of problem is the continuing limitation on utility liability in case of an accident at a nuclear power plant, which is provided by the federal government through the Price-Anderson Act. This intervention has been maintained well beyond the years of the nuclear power industry's infancy. The difficulties the federal government had in removing itself from the synthetic rubber industry during the decade after World War II testify as well to these problems (see Appendix E).

Efforts should be made to minimize these problems by appropriately designing institutional and policy instruments from the beginning. Incentives are needed for the achievement of cost-effectiveness, and periodic program review by Congress and high-level ERDA officials at significant milestones and decision points. Perhaps automatic termination of some government subsidies could be embodied from the start. Such measures would not guarantee avoidance of the identified pitfalls, but they would reduce the likelihood of being trapped in them. The overriding need is a clear commitment to limited demonstration and information-gathering objectives.

This issue rises partly out of the lack of clarity of the relationship between a successful demonstration and a successful industry, and an unfounded assumption that the second will automatically flow smoothly out of the first. In fact, this is not necessarily so, for the conditions and criteria for a successful demonstration may well be vastly different from those for a successful industry. Inherent in the market place are successes and failures, and trials and errors; it is only after such traumas that a new industry attains relative stability. Seldom do the industry pioneers remain as leaders in the mature industry. If ERDA or any other government agency is to "select" projects or processes for commercialization, rather than allowing the market to permit them to emerge, then ERDA must assess the real risks of alternatives, and allow those to fail which should fail by market criteria.

Underlying these issues is the fact that the U.S. government lacks not only the tools but, fundamentally, it lacks the cultural framework in which to effect energy policy through detailed involvement in the marketplace. Traditionally, we have looked to the marketplace to solve long-range energy problems, and to the government (primarily through regulation and tax policy) only to see that the marketplace does not yield unacceptable environmental or distributional effects. Only in short-term crises has there been detailed intervention, and we are very short on either experience or precedent for the establishment by government of long-term policy direction of the solution of economic problems by the private sector. Other countries, of course, have different forms of private-public intervention, and it is always possible that fundamental changes can be wrought in the political economy of the U.S. For better or worse, however, we appear likely to stay with the market-oriented institutions we have. The challenge is to adapt them to this new and different situation in the energy sector.

4.3.3 Anti-trust and the Issue of "Bigness"

In many cases it is only the large established firms that will be able to achieve a widespread and speedy market penetration of new technologies. For example, loan guarantees for the commercialization of a new automotive powerplant will not bring forward a fifth domestic auto manufacturer--the tremendous capital requirements required for such an attempted entry will not be met, even with a partial government debt guarantee. Careful planning will be required in such circumstances to insure that federal programs do not have the effect of decreasing the level of competition that exists now. For example, this concern might lead to the funding of redundant projects, where the advantages of competition are seen to outweigh the increased costs of duplication.[1]

But this does not resolve a different issue. Inevitably, many or most of the demonstration plants will be built with some form of subsidy by large, well-known companies, some of whom are unfavorably regarded by important segments of the electorate. The new plants will make some very big firms even bigger, and many persons would equate greater size with more "power". There is a need to decide what steps we are willing to take, and can afford, not merely to foster competition but to insure that large companies do not get more of the program than is socially desirable. Given the current political climate regarding the large oil companies and the tradition of strong Congressional support for small businesses, this is an especially important issue.

A further anti-trust problem is that of group action. There may well be instances where commercialization of energy technology would best be expedited through cooperation and information exchange among the firms in a particular industry. A prudent management would be deterred by even a low probability of a finding of criminal violation, or even a moderate probability that a suit would be filed, with the accompanying publicity. Yet the anti-trust agencies, if they could devote adequate time to the problem, might see no violation. The problem is basically one of fact: Will the proposed group activity have any undesirable effect on supply and market price? In order to avoid the harmful results of uncertainty about the government's actions, it would be well to seek anti-trust clearance at an early stage.

---

[1]See Economic Strategy for Developing Nuclear Breeder Reactors, P.W. MacAvoy (M.I.T. Press, 1969) for a detailed evaluation of the breeder reactor case where he reaches just this conclusion.

The "bigness" problem is not new, and has been often resolved in particular cases. A satisfactory way of handling it may be difficult to obtain at the present time. However, as discussed above, the situation depends on a variety of essentially political factors that bear little or no relation to the importance of such an exemption to the success of new technologies.

4.4 MECHANISMS OF SUPPORT

The institutional problems inherent in a commercial demonstration program are, as we have seen, formidable. The latter must be taken into account, however, in the choice of instruments for subsidizing commercial-scale plants. This is the issue we now address: How should the government go about providing the incentives which will result in the construction of the plants?

4.4.1 General Considerations

We have argued that the purposes of government-supported commercial demonstration projects are principally (1) to support the development of the information associated with the resolution of the technical and institutional uncertainties concerning new energy technologies, and (2) to provide a subsidy to foster the introduction of such technologies when they are being retarded by inappropriate energy prices. With these goals in mind, some general considerations of program design can be laid out.

Both goals lead to an argument that commercial demonstrations should be conducted in such a way as to simulate the normal workings of the private sector--i.e., the influence of the subsidy should be as small as possible and still lower the costs of the actual demonstration to the point where it will go ahead. This implies that the participants in the program should be those who would be dealing with the technology under circumstances of widespread use, and that the incentive structure associated with their participation should approximate that which they will face after the government program is over.

The choice of industrial participants must focus on those firms which show the clearest promise for long-term involvement in the industry (taking into account the "bigness" issue). As stated by the recent Rand study: "Demonstration projects that enjoy greater diffusion success are those operating with a strong technology delivery system."[1] These firms will have the incentive to make the technology a long-term economic success. Furthermore, the very prospect of such success will stimulate the initiation of the relevant regulatory and institutional proceedings.

The importance of a careful choice of industrial participants can be seen when we considered that there are strategies that would be profitable to some segments of industry, but would fail to accomplish the goals of commercial demonstration. That is to say, the construction and operation of government-supported demonstration plants can be seen as a business in itself quite apart from the ultimate development of viable industries. For example, if the variance in construction costs is very high (as may often be the case), substantial profit at low risk is possible for construction operating on a cost-plus basis; this fact will tend to attract much interest in the construction of demonstration plants, beyond that stemming from the prospect of their future profitable operation.

[1]"Analysis of Federally Funded Demonstration Projects: Final Report" (The Rand Corporation, Santa Monica, California, April, 1976), Report R-1926-DOC, p. 51.

Thus the federal program should provide the project managers with a structure of incentives which differs as little as possible from that which they would face in an unsubsidized circumstance. This is important with respect to the choice of the mix of input factors--especially capital as compared with labor, transportation, maintenance, etc. Similarly, the incentives with respect to risk-taking should be as realistic as possible.

There also is a need to foster the spread of the appropriate learning involved in the first few plants and to stimulate competition in the field, and here there will be a trade-off between the number of firms involved and the cost of the program. This trade-off, while clear conceptually, is difficult to evaluate analytically. Many of the issues addressed in Section 5 are relevant, in that the linkages between the government's program and the rate of technological substitution are not well understood; in particular, not much is known about the importance of having a number of firms involved, as opposed to just one.

Clearly any commercial demonstration program must be carefully branded as such. Projects must be chosen so that early government subsidies to private firms can be turned off when the demonstration has been completed. There is a "slippery slope" here, on which commercial demonstration programs may slide into long-term subsidies. Likewise, the government agency must have a clearly bounded authority, and a sense that its mission is accomplished when the demonstration projects are set up and the industry is ready to stand or fall on its own. Avoiding the "slippery slope" should be an important consideration in choosing subsidy mechanisms, though it is difficult to subject this effect to precise analysis.

Simiarly, there is a need for flexibility in program design. One of the principal goals of commercial demonstration programs is the development of information which is crucial to the long-term success of the new industry, and it follows that this information may have important implications for the demonstration program itself. For example, a technology might be expected to be economically viable in the long run, while the requirements for environmental production are uncertain. During the course of a demonstration the environmental uncertainties might be clarified in a way that drove costs out of the range of economic feasibility. Obviously at that point there would be little utility in continuing the demonstration program (although of course, more fundamental research and development might well continue), and it is important to design subsidies that can be shut off in such a circumstance.

Finally, in order that the program be subjected to careful scrutiny, financing mechanisms should be used which reveal the full costs of the program. Indeed the full cost is one of the most important things the demonstration should be designed to determine. There will of course be large uncertainties in estimates of both the costs and the benefits of such programs. But, as discussed below, some demonstration schemes provide greater visibility of cost than others. Clearly, if the extent of the subsidy is not well known, then the cost of the technologies output cannot be readily calculated. If this is the case, then an uncertainty of major significance will remain.

While the true (total) cost of the project from a subsidized commercial demonstration plant may be determined by this type of program, the long-run cost may not be developed in any case. As discussed above, the cost of the demonstration plant is likely to be higher than that of subsequent plants--otherwise the commercial demonstration program would be of little utility. On the other hand, a firm planning to use the subsidized demonstration plant as a foothold in a new industry may well sell the plant's product below cost (even counting the subsidy), expecting to make back its losses on subsequent profits in the industry. Once again, the complex dynamics of the commercialization process may make analysis difficult.

4.4.2 Financial Instruments for Supporting Commercial Demonstration Projects

After weighing the general considerations discussed above, a specific program format and set of financial instruments must be chosen. The proper selection and design of the subsidy mechanism may differ from industry to industry, technology to technology, and even from project to project; and therefore a detailed analysis of the issue is beyond the scope of this study. It is possible, on the other hand, to make some general observations about the different approaches.

We begin with loan guarantees, which we have looked at in greater detail than the others because of the large-scale programs currently being proposed. Our discussion of this mechanism indicates the types of issues that need to be better understood about all forms of subsidy. We also look briefly at regulated utilities which can be used as a subsidy mechanism, and comment on tax expenditures, direct government expenditures, and price guarantees.

(i) Loan Guarantees

Loan guarantees are a widely discussed commercial demonstration incentive because, among other things, they provide an off-budget form of financing. However, the use of loan guarantees has been subjected to very little analysis, particularly of their true costs and some of their subtle incentive effects. A loan guarantee appears to be free to the government. When it is estimated that there is a small probability of default and, with a small number of plants, it appears there might be no budgetary cost at all. But this does not mean that the guarantee is costless to the society. Obviously the principal effect of the guarantee is to shift capital from other less risky projects into the guaranteed project, making capital slightly more expensive for all competing investments. The government has done this by absorbing the risk of default, and the cost is distributed throughout capital markets. The problem of analyzing just what this cost actually is makes the use of this incentive very difficult to evaluate. (We make some suggestions about possible approaches to the problem in Section 5.)

There are other effects as well. Subsidizing risky ventures by means of debt guarantees induces high debt ratios. If privately financed as independent ventures, they would use very little debt.[1] If this avoidance of debt is rational, then one must presume that there are costs of inducing ventures to operate at unusually high debt ratios.[2] This may induce inappropriate operating and investment decisions. Two examples follow.

(a) The existence of risky debt creates a disincentive for follow-on investments. Few ventures operate forward on one initial capital outlay. Follow-on investments are often required for expansion, to cope with unexpected difficulties, etc. These follow-on investments are undertaken because they generate a net increase in the present value of the firms' assets. However,

---

[1]They might be undertaken directly by firms which already have substantial debt outstanding. But the new venture would not be regarded as "supporting" any substantial amount of additional borrowing.

[2]It might be argued that risky ventures operate at low debt ratios for the simple reason that investors do not wish to hold risky debt. If this is the only reason then there is no harm in debt guarantees. But there is no reason why risk per se should preclude a market for a firm's bonds. There is an ample market for convertible bonds, for example, which in many ways are similar to straight bonds with a high probability of default. That is, in each case the bonds' market values are highly sensitive to changes in the values of the firm's assets.

the existence of risky debt weakens the incentive for the owners of the firm to make such investments, because part of the increase in asset value is captured by the investors who hold the risky debt.

To take a concrete example, suppose that technical programs are discovered in the initial production runs of a synthetic oil plant. The owners can live with the problems or make a substantial additional investment to solve them. Under normal circumstances the owner would simply ask whether solving the problem increased the plant's present value by more than the investment required. However, in this case there is a large amount of risky debt outstanding, with the government bearing the risk. If the investment is made, the value of the plant increases, and the unguaranteed value of the debt increases also. The government is clearly better off if the additional investment is made.

But if the government captures, say, 20 percent of the value created by the additional investment, that leaves only 80 percent for the plant's owners. They put up 100 percent of the incremental outlay and get only 80 percent of the incremental gain. The incentive for them to make sensible investment decisions is correspondingly weakened. The percent of the increase in asset values captured by lenders depends on how risky their debt is. The riskier the debt the more they capture, and the weaker the incentive for economically sound follow-on investments.

This problem of warped investment incentives exists for any risky debt, whether or not government guaranteed. It is not usually serious, since lenders are careful not to purchase debt claims when there is a high probability of default. They are particularly cautious when the probability of payment is likely to depend on further discretionary outlays by the firm's owners. Lenders recognize that the owners may choose not to advance cash for those outlays, and protect themselves accordingly.

The problem is likely to be much more serious for ventures in commercialization. The offer of debt guarantees will induce debt ratios as high as those of the largest regulated utilities. Yet the underlying assets are viewed as unusually risky even for unregulated firms. The debt of such a firm is, absent the guarantee, a speculative instrument. Consequently the incentive effects will be strong, and very likely improper from an economic standpoint.[1]

Where there is a disincentive for follow-on investment, there is also an incentive for disinvestment. That is, owners gain by liquidating assets and paying dividends. The value of the firm declines by the amount of dividend paid, but part of the decline is "captured" by the risk debt. Bondholders incur a capital loss, because the assets securing their claim are less valuable. This capital loss is the owners' gain. The value of equity declines by less than the cash dividend received.

Similarly, equity gains if additional debt can be issued later in the venture's life. Any increase in the venture's debt ratio increases the risk of initially outstanding debt and causes a capital loss to the initial lenders (to the government, in this case).

This suggests another difficulty with loan guarantees. In normal private financing, bond indentures are carefully written to preclude the kinds of maneuvers just described. Dividend payments and additional debt issues are restricted, as well as a variety of other strategies that would have the same

[1]There are various ways of alleviating the incentive effects, but none seem to apply here. For example, the follow-on investment could be part debt financed. Since the additional debt dilutes the government's claim on assets, the new financing could be arranged to leave the government's position unchanged. Who would buy the additional debt? The reason we need the government guarantee is that private markets avoid debt when it is as risky as the debt we are contemplating here. The government could guarantee the new debt as well, of course, but we doubt ERDA is willing to assume any such open-minded commitment, in which the firm can come back for more subsidy any time a follow-on investment is contemplated.

effect.[1]

Moreover, private lenders monitor the firm's actions to check for actions that violate the spirit or the letter of the indenture provisions.[2] The indenture restrictions and monitoring reduce the likelihood of the behavior described above. But with a government guarantee, private lenders have no incentive to work out appropriate indenture restrictions or to monitor the venture being financed. Moreover, the proposed procedure for loan guarantees contains no explicit equivalent procedure. If indenture restrictions and monitoring are no one's responsibility, then we can expect the various incentive effects described above to operate unchecked in commercialization ventures.

(b) Loan guarantees encourage high risk technology and operating procedure. It is no doubt obvious from what is said above that loan guarantees are worth more to risky ventures than safe ones. The riskier the asset, the larger the different between the guaranteed and unguaranteed value of the debt claim, and the larger the subsidy. Similarly, the loan guarantee creates an incentive for a commercialization venture to be operated by risky strategies rather than safe ones, and for concentrating follow-on investments in relatively risky assets. Anything that makes outstanding debt riskier benefits the venture's owners, other things equal. Finally, the loan guarantees should encourage owners of commercialization ventures to set them up as separately incorporated ventures, so that there are as few assets securing the debt as possible. This maximizes

---

[1] The disincentive effect of risky debt on follow-on investment is harder to prevent by indenture provisions, since it is difficult for any outsider to determine what the firm's investment opportunities are, or whether any particular opportunity has a positive net present value.

[2] If only the spirit is violated, lenders nevertheless have options open. For example, it is often possible to find a technicality justifying the lenders in declaring that the loan is in default.

the value of the loan-guarantee subsidy, and reduces the owners' exposure and commitment to the venture.

Of course these incentives exist in private financing as well, but they are magnified by the extremely high debt ratios contemplated in the commercialization program, and by the apparent lack of concern for developing appropriate indenture restrictions and monitoring.

Consequently, the subsidy inherent in loan guarantees is not neutral. It favors high risk investment and operating strategies. Now it might be argued that this is exactly what ERDA wants. It is true that the technologies ERDA chooses to support in commercial demonstration will be risky ones--for reasons we have discussed. Here, however, we are dealing with distorted incentives to the operator given the technical option which is subsidized. Under these circumstances a neutral effect of the support is the desired attribute.

(ii) Financing by Regulated Utilities

A number of important energy industries are under price regulation, and this circumstance offers an opportunity for financing demonstration projects--mainly for the regulated industry itself, but not necessarily so limited. In most of these industries, such as natural gas or electric power, the price is set on the basis of average cost of supply. This makes it possible to finance small increments of extremely high cost energy supply, for when rolled into the overall rate structure the price effect felt by consumers is not very great. Of course, managers of regulatory utilities operate under a mandate to serve customers at least cost and normally they would not adopt (nor would regulatory conditions allow them to adopt) supply technologies which were significantly more costly than available alternatives.

In certain cases, however, price regulation can lead to a circumstance where technologies of almost any cost might be financed (and gladly) by regulated utilities. This occurs in the case of natural gas, for example, where the price of gas in interstate markets is being held below either the price of gas within the producing states or the price of alternative fuels at the point of consumption. As a result, very little new gas is being committed to interstate markets; reserves committed to these markets are declining; and consumers face a choice of switching from cheap gas to high priced oil. Utilities do not really have an option to bid for moderately priced gas. Where excess demand is created by price regulation in this manner, it would be possible to finance a very high cost addition to supply.

Thus these regulatory procedures offer an opportunity to finance commercial demonstrations, and in this circumstance two issues arise: one involves efficiency and the other equity. First, the fact of active consumer desire for the output of a demonstration facility may give a strong push to the use of this particular situation as a demonstration format. Given the likely difficulties in subsidizing demonstration activities by the instruments listed above, it is possible that a significant bias might be introduced into the commercialization program. Technologies and schemes might be financed which are not the most efficient in terms of their ability to open up new options for the country as a whole.

The second issue is the one of equity. Since the knowledge gained by such a demonstration will benefit the nation, it can be argued that the burden of the subsidy of the initial demonstration ought to fall on the nation's taxpayers. If demonstrations are financed by rolling the cost into the rates of a particular regulated utility, then the burden of the demonstration (and the risks of very high cost) are targeted specifically to the consumers of that utility system. As noted earlier, larger issues of utility rate regulation, which lead to significant excess demand, may create a situation where the utilities seek these projects since they cannot satisfy their excess demand otherwise. Nevertheless, the issue remains as to whether the resulting distribution of economic impact among the customers is a desirable one.

(iii) Tax Expenditures.

A widely discussed method of subsidy is to lower taxes on a given kind of investment, by tax credit or accelerated depreciation. It appears to be costless because the sudsidy does not enter the federal budget. (Of course, the burden is reflected in taxes foregone.) This method seems to be preferred by a number of large corporations who are considering synthetic fuel plants.[1]

Tax expenditures suffer several disadvantages, under the criteria laid out above. First, because the subsidy is indirect, its magnitude may be very hard to identify. One of the most important objectives of a demonstration (i.e., information about cost) is lost. Moreover, the most common forms of tax expenditure for the types of investments involved here are the investment tax credit and/or accelerated depreciation. Both are subsidies to capital--as opposed to materials and labor cost--and therefore they introduce a bias into the selection of factor inputs.

Finally, there is an important institutional problem. It might prove very difficult to target tax expenditures to a small number of particular demonstration plants; the subsidy might end up being applied to many projects that were not part of the R,D&D program. Also, in the past it has proved very

[1]"Response to Questions on Government Incentives for Synfuels Plants," Exxon, U.S.A., in Loan Guarantees for Commercial-Size Synthetic Fuels Demonstration Plants, Volume III (U.S. House of Resentatives Committee on Science and Technology, September and October, 1976, No. 36), p. 2834.

difficult to turn off tax expenditure programs, even after their original justification had faded from the scene.

(iv) <u>Direct Government Expenditures</u>

Other methods of subsidy include sharing of cost between governments and private companies, direct grants to builders or operators, or government construction with private operation and an eventual sale (or offer of first refusal) to the private operator. One finds examples of these methods in World War II. Unfortunately, one cannot claim that there is any "usable past" from which to draw lessons. Appendix D examines the case of synthetic rubber during World War II. It is shown there that that experience bears little relevance to the present problem because of the undeniable "gaps" that had to be filled at "any" cost, and the many economic controls that characterized the war-time years. That data do not exist to support serious analysis of the efficiency of the effort, in spite of the fact that in meeting its own goals the program was widely judged to be a success. Direct cash grants have the obvious advantage of making the extent of the subsidy clearly visible and of not biasing input factor choices. On the other hand, direct government construction and ownership, even if followed by sale to private industry, does not simulate the market situation.

(v) <u>Price Guarantees</u>

A price guarantee has the great advantage of leaving the private firm free to design the demonstration plant as it wishes, in order to minimize total outlays and maximize profits. Thus market situations are minimally distorted.

Furthermore, the extent of the subsidy is very visible, allowing the clearest calculations of the full private cost of the product.

These characteristics make the price guarantee a very attractive instrument, under the criteria laid out above. Of course, there are many ways to design and manage such schemes, as there are with all these approaches, and their detailed formulation would depend on the facts of the particular program.

5. EVALUATION AND PLANNING

The previous sections reviewed the nature of the investment process by which most technologies are adopted in our economy, and surveyed the situations where government intervention may be called for and the policy instruments available. Next, we come to the issue of how federal officials can evaluate alternative situations which appear to call for intervention, and the procedures by which the year-to-year activities might be planned and monitored.

To study the problems that arise in connection with this evaluation and planning task, we will go through a two-part discussion. First, we explore the nature of the evaluation problem and how, in principle, calculations and judgements might be made. As is evident from the discussion in the preceding sections, the possible technological and market circumstances that such evaluations have to cover are very complex. Therefore, to facilitate the discussion of the analysis issues, a set of simple examples is used. Second, based on this layout of the evaluation problem, we consider the key steps in the required analysis and the availability of the techniques to perform the tasks that are implied. This inquiry leads to a set of areas where additional research and empirical analysis is needed to support attempts to evaluate and plan federal programs.

It should be repeated at the outset that our focus is on the evaluation problems as they present themselves at the stage of commercial demonstration or "commercialization" of new energy technologies. ERDA also faces a larger planning and evaluation task which includes decisions that must be made about expenditures on development of various technologies and on basic research or invention-type activities. Consideration of the larger planning, analysis, and review problem of such a federal agency is outside the scope of this study. However, it is hoped that the discussion of issues that arise at the introduction stage, and the evaluation techniques that may be applied there, will cast some light on similar tasks that need to be carried out for the ERDA strategy as a whole.

5.1 A SCHEMATIC REPRESENTATION OF THE INTRODUCTION STAGE

To facilitate discussion of the analytical problems that arise, a number of simplifying assumptions are called for. The resulting prototype situation will allow us to raise most of the conceptual issues that must be faced in constructing an evaluation methodology. Naturally, the basic approach outlined here would have to be modified to suit the special characteristics of particular technologies or market circumstances. The following is a formal summary of the economics of the process of technological change, as discussed in previous sections.

We assume that there is a particular technical option which has passed through the development stage, as defined in Section 3. A choice is now faced as to whether it should be introduced into commercial use. The technology, when put into use, produces an output of energy in each year of the future which we may denote by the variable x_t. This product may be energy produced by a new supply technology, such as shale oil or solar heating; it may also be thought of as energy saved by some new utilization device, such as a new automotive engine. From time to time during this discussion of these three examples-- shale oil, solar household heating, and advanced automotive engines-- will be used to illustrate the application of the analysis to different types of circumstances. Further, it helps to assume that several other conditions hold true:

1. There is only one market in which the good is sold. That is, there are no complex sets of markets differentiated by weather or geography. Furthermore, the demand for the technology is a simple function of price: there are no considerations of consumer acceptance apart from cost as price (as might be the case, for example, if solar collectors were cheaper than other methods of space heating, but consumers did not like the looks of them).

2. The technology produces only one well-defined product, such as synthetic oil gasoline saved, or Btu's in home heating. Many technologies, of course, produce a variety of products, and to simplify the example we will leave those aside.

3. The process of technical change can be summarized along the lines laid out in Section 3 and shown in schematic form in Figure 5.1. The technology has been through the development stage and the firm faces an introduction decision. We define a clear step in the evolution of the technology which is referred to as "introduction". After the introduction into the market, new data will be available about the technology and its market propects, and at that point a new set of decisions will be made as to whether the technology ultimately diffuses through the market.

As it is evident, these are dramatic simplifications of reality. The introduction stage is an abstraction which may or may not be well distinguished from the processes of development and diffusion. However, since the federal programs under study here are concerned with this specific stage, this provides a useful way to focus on the decision to subsidize commercial demonstrations. Particular circumstances may involve more complex mixes of products and market circumstances, but these complications are best withheld until it is evident that headway can be made in the evaluation task in this more simplified circumstance.

5.2 THE NATURE OF THE EVALUATION PROBLEM

5.2.1 Elements of the Private Investment Decision

The various elements of the evaluation problem are laid out in Figure 5.1. We introduce some algebraic notation in the figure and accompanying text, but the symbols are no more than a shorthand. The logic is the same if the problem is to be approached with an elaborate set of analytical models or simply with common sense and a few key data elements. As shown in the figure, the circumstance is comprised of several elements. First, as noted earlier, the technology produces an output which we define by the variable x, or x_t when we speak of energy in some particular year t. For a shale oil plant we may speak of a facility that produces x barrels of oil in a year. Solar heating produces Btu's of heat directed to domestic heating, and that case x reflects the actual energy delivered. In the case of a new automobile engine, x can be taken to represent gallons of gasoline saved. While more precise definitions would be required before an adequate set of calculations could be made, these will suffice for our purposes.

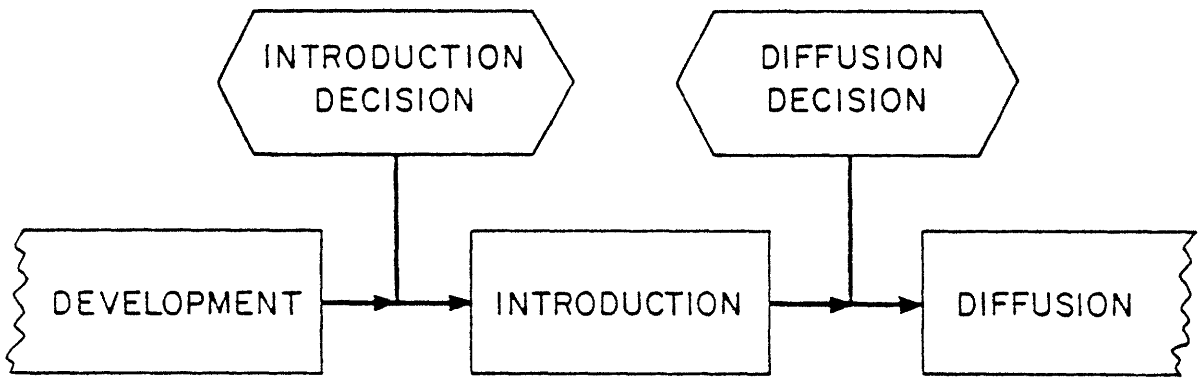
When these technologies have diffused and are in wide-scale use, the energy delivered and saved, x, will have some cost. This we refer to by the symbol C(x).[1] Of course at the time of an introduction decision, no one knows what that ultimate cost will be, but the dimensions may be stated in terms of ultimate dollars per barrel of the shale oil, cents per million BTU of the energy into household heating, or cents per gallon of gasoline

---

[1]Note that C(x) is the cost after the experience of commercial introduction and after some diffusion has taken place. This means that the term C(x) may involve learning effects and a host of other phenomena. We omit them here to simplfy the discussion.

Figure 5.1

KEY DECISIONS IN COMMERCIALIZATION



Probability of Ultimate Production Cost:	$G^i[C(x)]$	$G^d[C(x)]$
Actual Unit Production Cost:	$C^*(x^*)$	$C(x)$
Total Cost of Stage (net, gross):	K_n, K_g	

saved. Since this is a representation of the firm's investment decision, these costs are private costs only.

Although C(x) is not known at the point of the introduction decision, there is some expected cost of the technology which may be calculated on the basis of data obtained in the development stage, and using other information about market conditions, regulatory prospects, legal difficulties, and the like. As shown in Figure 5.1, we refer to the probability distribution of ultimate costs by the symbol $G^i[C(x)]$. In the case of a shale oil plant, for example, the distribution of likely ultimate costs may be very broad if the technology has not been tried at large scale. A typical range of values, given that regulatory difficulties are not expected to intervene, may be from \$15 per barrel to \$35 per barrel.[1] Under some regulatory circumstances, this distribution might extend to much higher values (or even to an infinite cost which would reflect a case where the technology was proven socially unacceptable).

The industries that are concerned with this technology have the information contained in $G^i[C(x)]$ as a result of their own development work or various federal R&D programs. They may take the next step in the technology change process by introducing the technical options into the market. In the case of a shale oil plant this would be to build the first commercial scale plant, or set of such facilities. For solar heating, the introduction step would involve the establishment of a commercial scale manufacturing facility and the setting up of the marketing apparatus necessary to fully explore its potential. As shown in Figure 5.1, we talk of this step as involving a net introduction cost, K_n. This is the net investment in the introduction

[1] These numbers are strictly hypothetical. We discuss actual costs in more detail in Appendix A.

stage, as discussed in Section 4.1. Introduction produces a set of facilities which can produce the annual energy product x*, each unit of which costs an average of C*(x*). Thus K_n equals the gross capital investment of the introduction stage, K_g, minus the net revenues produced from the sale of the annual production x* (all carefully discounted).

Using the language developed in Section 3, a firm buys two things if it decides to make the expenditure K_g:

(a) It buys the capacity to carry out production using the facilities built at the introduction stage, and to sell the resulting product in the market.

(b) It purchases the option to go into production for the diffusion stage if the conditions indicate.

Of course, the results of the introduction decision may be fortunate or unfortunate depending on the circumstances. It is possible that the facilities built at this stage will make a profit in and of themselves, and will lead the way to a profitable diffusion. Alternatively, and more likely, the investment K_g may not yield a reasonable rate of return if considered alone (that is, the first plant loses money). However it still may be a good investment because the option that comes along with it is sufficiently profitable to cover the introduction losses; that is, the value of the option is greater than K_n.

A more unhappy outcome would be where the results of the introduction were so unfavorable that plans for diffusion were abandoned. That is, an option to go on is made available by the investments at the introduction step, but the option is not taken up because its expected value is negative. An example here would be a solar heating option which was expected to achieve significant economies in scaling up to a commercial size plant, but where these economies were not in fact realized for reasons not fully foreseen before the introduction stage. As a result the resulting heating system is too expensive to capture a significant part of the household market.

The information available after the introduction has been tried is indicated by the distribution $G^d[C(x)]$ in Figure 5.1. This is a new probability distribution of costs of the recently marketed technology, and it is only available after investment in the commercial introduction step (and the net expenditure of K_n has taken place).

When a firm is making decisions about whether to invest in diffusion given $G^d[C(x)]$, or to invest in introduction given $G^i[C(x)]$, a key factor in its calculations is the expected market price of energy over the relevant time horizon--the "planning price" previously discussed. This we will refer to as P_t^m.[1] This price is, of course, uncertain. A separate price which will enter in other calculations is the social value of energy, which we denote here by P_t^s. This price or value is not of relevance to the private decision maker, though it will enter into the types of calculations that would be made by a federal agency in deciding what subsidies are warranted, as discussed below.

There are additional observations that are worth making about the relationshop between $G^i[C(x)]$ and $G^d[C(x)]$. In general, one hopes that each stage of investment in R,D&D--including the introduction stage--will lower the ultimate costs C(x) that are going to be experienced with a particular

---

[1]Throughout this discussion we simplify the market circumstance by talking as if there were a single energy price. There are, of course, a whole structure of prices depending upon the area of the country and the particular product involved. Calculation of such prices may offer its own set of difficulties, but there is a common exercise and adds no conceptual problems to the issues already under discussion here.

technology. But note that in this case both these expressions reflect expectations about what the ultimate cost of the technology will be after the diffusion stage has been entered. Thus, viewed from the standpoint of the introduction decision, there is no reason to suppose that the expected values of these two distributions of costs will be different. The shale oil example can serve to elaborate this point. Before a firm would introduce a plant at commercial scale, it would have some estimate of its expected cost in large-scale application in many plants. After it introduced the first round of plants, it would have some revised expectation of the cost of that technology over the 20 or 30 plants to follow. But at the point of introduction decision, it has no basis for knowing why this cost should be different after the experiments than before. Of course, it will be different in fact. But what we mean by the expected value of $G^i[C(x)]$ is precisely the best guess about what the cost will be after diffusion.

On the other hand, the firm will have opinions as to the likely changes in the dispersion of costs between an estimate at the introduction decision and an estimate after the introduction has been tried. Much of the justification for any federal involvement in the commercialization process, and indeed much of the justification for any corporate investment at this level, is that the net investment of K_n and the experience of the introduction experiment itself will serve to reduce the variance of $G[C(x)]$. This is what one means when it is said that the first commercial-scale plants will resolve uncertainties about scaling laws, environmental restrictions, labor problems, etc.[1]

---

[1]Of course, it should be noted that it is always possible that the variance in likely outcomes could increase. This would happen when the introduction experiment discovered new sources of uncertainty which were not foreseen at the time the estimates $G^i[C(x)]$ were made.

5.2.2 The Decision Faced by a Private Firm

With this simple model of the introduction and diffusion stages, we can review what was said earlier about the decision faced by a private firm. At the time of the introduction decision, the firm has a probability distribution of the ultimate costs of the technology in diffusion, $G^i[C(x)]$. It also has the prospect of an investment (K_g), that will lead it to the diffusion stage. The firms faces what was earlier called an "investment choice". The expenditure K_g will be a good investment if the total of the returns from the diffusion stage (which may be zero if diffusion is not indicated) and the returns from facilities built during the introduction stage are sufficient to cover the cost K_g. This calculation, of course, is ultimately dependent on what the firm takes as its forecast of P_t^m and how uncertain the cost forecast is.

Naturally, the value of the diffusion option which is being purchased must be sufficiently high to allow for the riskiness of investing K_g. If the current estimate of ultimate costs and prices, $G^i[C(x)]$ and P_m^t, are highly uncertain, then the introduction investment is very risky and must have an expected return which is high enough to draw the firm's resources away from other investments.

In general, when such an investment is not made it is because the returns expected if the diffusion stage were entered are negative. This would be the case, for example, for a shale oil plant where the mean of $G^i[C(x)]$ is \$25 per barrel and the expected value of P_t^m is only \$15 per barrel. Or such would be the case for water heating where the cost of energy from the solar device to be \$15 per million Btu and cost of alternative energy (say. from a gas-fired water heater) to only \$3 per million Btu. Alternatively, the expected value of returns in the diffusion stage may be positive, but the costs of the introduction stage alone may be so great as to make the overall prospects unattractive (i.e., the expected net present value of introduction is negative).

On the other hand, as noted in Section 3.2, there are circumstances where the market system may "fail" in the sense that corporate decisions at this stage are based on considerations which do not reflect the social benefits and costs of the actions to be taken. We discuss several such prospects below, using concepts discussed in Section 3:

1. P_t^m may be less than P_t^s. This might be due to price controls or to the national security premium. It would lead to a circumstance where firms had no interest in carrying out the introduction investment even though such an advance might be shown to be socially desirable. Of course, the fact that the federal government may be able to bring about such an investment at the introduction stage does not mean that diffusion will take place. Private decision makers will still be faced with a diffusion decision based on P_t^m.

2. Inability to appropriate technical results. In terms of Figure 5.1 this would hold where no firm investing in K_g could expect to capture enough of the market to take advantage of the information a $G^d[C(x)]$, which would be gained by the introduction experiment.

3. Regulatory and political risks. These risks may give $G^i[C(x)]$ a high variance (particularly by introducing extreme low-end events into that distribution) and thus dramatically raise the risk premium which K_g must promise to earn. To the extent that these uncertainties are artificially imposed, they constitute a "failure" under the definition above.

4. Market structure. The lack of competitive pressure may lead some firms to forego investments in innovation which would be socially profitable.

5. Risk and financial markets. The dispersion of $G^i[C(x)]$ and uncertainties in P_t^m may be so large and the gross size of the investment K_g so great that corporate managers forego the introduction, even though a careful expected value calculation (including discounts for risk) predicts a positive return.

5.2.3 Evaluation of the Benefits of Government Intervention

Most of the instruments discussed in Section 4 are methods for subsidizing the cost K_g. A need for such support would be indicated by evidence of one of the market failures noted above. The ultimate decision to go ahead with the federal subsidy would depend on a calculation of the costs and benefits of the expenditure involved.[1]

To see the nature of the evaluation problem, we may pursue our simple example another step. Assume that for some reason the introduction investment will not be taken by private industry. The precise reasons why this is not happening need not concern us here (later we take up the case where introduction will eventually be undertaken by private capital, but the government may speed up the process through a subsidy). We may look first at the evaluation of the benefits of a direct federal expenditure of K_n. Later, we return to look at the issues raised by the calculation of cost, for the actual estimate of K_n may vary depending on the particular financial instrument achieved to bring the investment about. For now, however, assume that K_n is a simple direct federal expenditure.

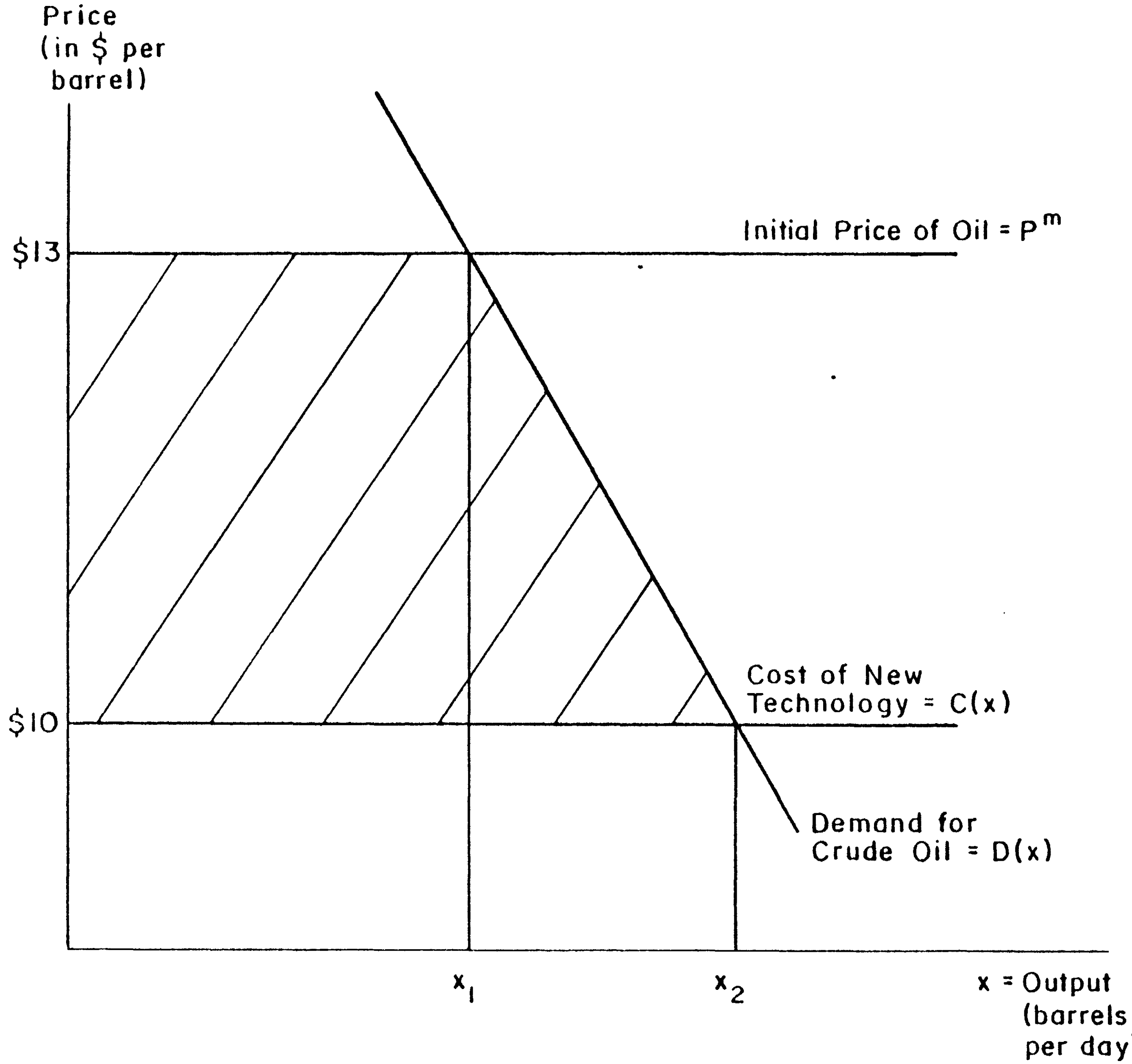
Case 1. Prices and Costs are Known with Certainty, Instantaneous Diffusion, No Social Premium on Energy. Suppose that the real price of imported oil is $13 per barrel and that this price will prevail for the foreseeable future. No extra value is attributed to independence from insecure energy sources, so that the imported price is the social cost. Also suppose that the shale oil plant we are using as an example can produce oil at a cost of $20 per barrel with the first plant and that, because of what it learned, all subsequent

[1] That is, there may be "failures" that are not worth correcting, given the opportunity costs of the resources required.

units are expected to produce at a cost of \$10 per barrel. That is, $C^*(x^*) =$ \$20 per barrel but the means of $G^i[C(x)]$ and $G^d[C(x)]$ are \$10 per barrel.

If new firms can take advantage of the learning and produce at \$10, and new plants can be built very quickly, then the price of all crude oil will fall to \$10. Thus it will be impossible for the first investor to recover the introduction investment and no individual firm will undertake the initial expenditure K_g. Nevertheless, society clearly stands to gain a great deal from having the price of oil reduced to \$10 per barrel. Here is a clear market failure: the returns to the initial investment are not appropriable. The societal returns come in the form of consumers' surplus--i.e., consumers pay less for energy.

We illustrate the case with Figure 5.2. In this diagram that market price of energy, P^m (assumed here to be independent of the time after introduction), is measured on vertical axis and quantities produced and consumed on the horizontal axis. The P_{oil} line illustrates the assumption that oil is available in any quantity we want at a price set by the international cartel. The line $C(x)$ demonstrates that with the new technology, we could produce any quantity desired at a cost pf \$10. Finally, the $D(x)$ curve indicates what quantities would be consumed at various prices. As price declines, more energy is consumed. The result then of lowering the cost to consumers from P_{oil} to $C(x)$ is an expansion in the amount consumed. We can measure the benefits as the shaded area. This area represents the difference between what consumers pay for oil, $P^m = C(x)$, and what they would have been



CALCULATION OF COMMERCIALIZATION PROGRAM BENEFITS

Figure 5.2

willing to pay for each unit. This is the change in "consumers' surplus" and represents the benefits to society.[1]

In this example, we assume that the investment will not take place without government intervention (without specifying why). In a real situation, the first analytical need would be to forecast actions of private investors in the absence of intervention, as well as the likely behavior after the intervention. As we have seen, it is the incremental changes due to the intervention that constitute the benefits of the government action. In order to be able to simulate this behavior, we need an understanding of why the market is not functioning. It is obvious, for example, that in reality, entry to the new industry will not occur instantaneously as in the example. Therefore all knowledge produced will not be inappropriable, and in this simple example we would expect some private investment to eventually take place in the absence of intervention. Nevertheless, if some benefits are inappropriable, investment will be less than desired and the timing may be delayed. More accurate descriptions of private incentives are needed in order to understand what will ensue from government intervention and what is the necessary level of subsidy.

Case 2. No Diffusion. Once we understand the market structure, the key to the decision analyses is distribution of costs of production $G[C(x)]$ and prices of delived output P^m. The profitability of government intervention in Case 1 revolves around the price of energy before the new technology,

---

[1]The cost of obtaining these benefits is the amount of the initial subsidy. Note, however, that this example is highly simplified. The cost of the new technology might depend on the rate of output. Also, technologies based on depleted resources will exhibit rising costs as the cheapest deposits are depleted, unless new technologies are developed. These issues will be taken up below.

the initial cost of the technology, and the cost of the technology after the introduction stage. If, for example, we change the above example so that the new option will produce energy at a cost of $14 per barrel once we build the first plant, the evaluation changes dramatically. The government subsidy no longer yields positive benefits. Now we lose $7 per barrel on the initial plant, but wind up at a situation where the price of energy is no lower than $13 per barrel. There has been no return to consumers, producers are no better off, and the government has lost its initial subsidy. We may have learned a great deal about the technology and the environmental and institutional barriers, but the knowledge is not worth anything in the market.

Clearly, prices need not be static. If oil prices rise, the situation changes. Then $14 oil might, in fact, ultimately prove economic and the returns to the subsidy would be positive.

In summary, we need to know (a) what the energy price P^m will be in the absence of the technology, and with it; (b) what initial subsidy is necessary to encourage the first plant; (c) what the cost of subsequent plants will be; and (d) what quantities will be demanded. We would then simulate behavior before and after the intervention and sum the benefits to consumers and producers as a whole. To know (a), (c), and (d), we need information on the supply curves for the new technology, the old energy source, and the demand curve. To know (b), we must understand the nature of the market failure. We will return to these issues in Section 5.3 below.

Case 3. Diffusion over Time. To approach a step closer to reality we assume that the market price of energy, P^m, will continue to be set by imports of oil, because the new technique will not instantaneously diffuse to take over the entire import volume. The crux of the analysis then is the forecasting of x_t given $G^i[C(x)]$ and an estimate of P^m. During the period when the market price is greater than the cost of the new option there is another component of the social benefits (besides consumers' surplus). This is producers' surplus--the difference between the selling price of the new product and its cost.

Case 4. Uncertain Prices, Uncertain Costs, Diffusion over Time. In Cases 1, 2, and 3 we treat the problem as a simple calculation under complete certainty about future prices and costs. Of course, such certainty never exists and decisions must be made without full knowledge of future prices and costs. The problem then becomes more complicated. A planner will have an expected market price, but will realize that the actual price P^m could vary within a wide range. Similarly, as discussed earlier, the costs for the initial plant, K_g, will be uncertain as well as costs of production from subsequent units $G[C(x)]$. In this case, the evaluation will be made based on expected costs and benefits.

Let us extend our example to encompass this case. Assume that in the future the real price of oil as set by the cartel is most likely to be \$13 per barrel but could be as low as \$5 and as high as \$20. Assume also that the product costs from subsequent plants are expected to be \$10, but could be as high as \$20 and as low as \$5. Let us make these ranges more precise by attaching a 1/2 probability to the medium and 1/4 probability to each of the extremes. We then have the probabilities for each outcome shown in Table 5.1. There is a return to the initial subsidy attached to each possible outcome. If the cost of the technology turns out to be no less than the price of oil, the return is zero or negative. If the cost is less, there is a positive return. The total returns will depend on the output levels for the new technology over time, x_t, given by demand conditions and the associated pace of diffusion of the new technology.

Table 5.1

PROBABILITY OF EACH COMBINATION OF POSSIBLE OIL PRICE AND NEW TECHNOLOGY COST

$G^i[C(x)]$ Technology Cost (Probability of Occurance)		Price of Oil P^m (Probability of Occurrence)		
		\$5(.25)	\$13(.5)	\$20(.25)
	\$5(.25)	.0625	.125	.0625
	\$10(.5)	.125	.25	.125
	\$20(.25)	.0625	.125	.0625

The probability information may be incorporated into our framework as follows. The joint probabilities of the price of oil and the cost of the new technology being a particular value is given in Table 5.1. Assume that the cost of output from the first plant, $C^*(x^*)$, is known with certainty. There are nine possible benefit outcomes and three possible cost outcomes. The expected net benefits are found by summing the two sets of outcomes weighted by the probability of occurance. Thus:

$$\text{Expected net social benefits} = \sum_{i=1}^{9} P_i B_i - \sum_{j=1}^{3} P_j C_j$$

where P_i, P_j, are the probabilities of occurrence and B_i, C_j are the results of evaluating the costs and benefits using the analysis developed in the previous three cases.

Case 5. Government Speedup of Introduction, No Social Premium on Energy. In actuality, of course, many (if not most) of the technical options supported in government commercialization programs would ultimately be introduced into the market without the subsidy--the government only accelerates the process. Thus a crucial analytical issue becomes industry's behavior without the government subsidy. The benefit analyses then become more complex, with the difference in the timing of the benefit streams due to government's investment taking the place of the total benefit associated with the new technique.

Case 6. Premium on Energy. Finally, there is the additional but crucial evaluation issue associated with the fact that the market price of energy is not likely to reflect its social value. As discussed earlier, this will likely be due to government price controls and the benefits of reducing imports.

In this case the increased availability of domestic supplies, increased conservation, and reduction of imports need to be valued not at the market price, but at the social value. The analysis of private investment decisions continues, of course, to be made at the market price.

---

[1] The decision, of course, need not be made only on the basis of this simple expected payoff. Even if the expected payoff were negative, we might be willing to undertake the program just to be sure that if price goes to $20 per barrel, we have the new technology available. In a world of uncertainty, of course, private firms will be willing to speculate on higher prices. However, institutional constraints often prevent the price from rising to a level that clears the market. Private firms will therefore not invest enough in the new technology and the government could provide insurance. In this case, we would have to compare this form of insurance to other alternatives to make sure this is the cheapest way for the country to purchase protection.

Case 7. The Government Waits. The discussion so far has treated the problem as if the decision to subsidize or not must be made now. This, of couse, is unrealistic. An important variable under the decision maker's control is when to invest. Are we much better off waiting? What do we gain (or lose) by waiting? Several things can make it worthwhile to wait. If there are new technologies under development that offer the hope of lower costs, it clearly can pay to wait. Also, more can be discovered about the future costs and prices, thus changing the probability distributions described in Case 4. The risk of an investment-cum-subsidy program can be reduced as future outcomes become clearer. Of course, it is possible nothing will become clearer. For example, uncertainty about P^m due to lack of information about the oil cartel behavior might remain high. No new technology might appear promising. In this case, there is no reason to wait.

5.3 THE STATE-OF-THE ART OF ANALYSIS

The previous discussion, and the simple cases used to illustrate the problems of analysis, lead to the identification of several areas of analysis and forecasting which are crucial to the evaluation of schemes of federal intervention in commercial demonstration. All analytical efforts which attempt to evaluate national income benefits from this type of investment must deal with these issues in one way or another. As might be expected from the sheer complexity of the problem, these constitute key areas for future research and analysis in an effort to improve our ability to analyze these circumstances. A brief discussion of the key problems follows; they constitute an agenda for research in this vital policy area.

5.3.1 Forecasts of Prices

As is evident from the cases presented here, a key input to all the analysis is a forecast of the market prices that will hold over the period when a technology might be introduced and diffused. In addition, the forecast of price needs to convey some notion of the rules of the game under which energy prices in general are being determined, as that will affect the likely response of private markets. In general, the analysis would be based on a single price (or a single distribution of prices) which would not be assumed to be affected by the commercialization investments under study, although as Case 1 illustrates there may be circumstances where the analysis would need to take account of such an effect by a new technology.

This emphasis on a price forecast was argued in Section 2, where it was stated that a key problem for ERDA planning is that the agency must incorporate some notion of likely future market conditions--and, in particular, some estimate of a "planning price"--in its analyses of commercialization investments. (Of course, the problem presented by the need to analyze ERDA planning decisions at the commercialization stage will appear in connection with earlier stages in R&D as well.) Without such a forecast of price, and perhaps other market conditions, it is not possible to distinguish clearly between technologies which may yield positive benefits if introduced and those which will not.

The forecast of market price ultimately depends on analysis of international oil markets, on the tariff or other policies that may be used to buffer the U.S. economy from these prices, and on the process of price formation in product and region markets throughout the economy. Some steps in this process are well understood, others are not. Overall, this is a key area for further research and analysis because of its importance to the evaluation procedure discussed above.

In addition, for evaluation purposes one also needs a forecast of a companion price to go along with the market price forecast--this price to reflect the social value of energy produced or saved. As discussed in Section 3.3.1 above, the social value of energy may depart from the market price. With respect to domestic petroleum, it seems clear that the social value is at least the price of landed imports--OPEC is the source of marginal supplies to the United States and will remain so for some time to come. It is argued in Section 3.3.2 that in fact the social value is even higher--that there is a national security premium associated with our dependence on imports. The premium is the amount the United States would be willing to pay for a barrel of oil, above the imported price, to be free from the insecurity associated with it. Thus, some form of national security premium must be estimated to arrive at a social value.

One measure of the national security premium is given by the cost of a stockpile which would counteract the effect of the imports. Suppose, for the purpose of illustration, that all imports are equally insecure, and that a storage program can in fact provide a counteractive security to imports. Then clearly the size of the appropriate stockpile is a monotonically increasing function of the level of imports. At any given level of imports, the incremental cost of the stockpile associated with one more daily barrel of imported oil would then be the national security premium.

The appropriate stockpile size might be calculated as an optimum where the cost of maintaining the stockpile is traded off against the expected savings in the case of an embargo plus the value of the deterrent effect (i.e., the lowered probability of embargo). A more intuitive measure of the incremental stockpile cost can be found by assuming that the size of the stockpile should always be directly proportional to the level of imports; then the proportionality constant can be thought of as the period over which the stockpile could replace the imports. If the stockpile is chosen to provide N years of supply at the annual rate of imports I, if the cost of the stockpile is solely the opportunity cost of the capital investment in inventoried petroleum (i), and the petroleum is purchased at the international market price (P^m), then the annual cost of the stockpile for each barrel per year of imports is $L \times P^m \times N \times i$. Thus, the national security premium would be $N \times i$ per cent of the imported price. If the interest rate were 6% and a 1-year stockpile were deemed sufficient, then the premium on each barrel would be 6% of the landed cost. Of course this simple calculation misses many complicating factors in the international and domestic petroleum scene, but it illustrates that a social value based on reasonable assumptions and judgements could be constructed.

5.3.2. Analysis of the Diffusion Process

As shown in Case 3, the evaluation of the benefits of the more rapid introduction of new technology depends ultimately on forecasts of the diffusion of those technologies through the relevant energy markets. That is, given estimates of cost, $G^i[C(x)]$ or $G^d[C(x)]$, the analysis depends on some method for estimating x_t given these cost forecasts and the market price data discussed above.

In general, this step requires a set of methods for analyzing transportation, processing, and energy technology choice, so that one can simulate the way the economy adjusts to a new technology given that is has survived the introduction stage. These estimates may be made in a variety of ways--ranging from informed judgements and calculations to highly elaborated formal models. In the latter category, for example, efforts at Stanford Research Institute[1] and Brookhaven National Laboratory[2] provide a framework for conditional forecasting of the expected penetration of new and emerging energy technologies and products based on the cost and efficiency attributes of these technologies. The SRI-Gulf model is a network representation of the U.S. energy system which provides a very detailed description of the processing, conversion, and transportation activities required to process primary energy supplies (coal, oil, gas, and uranium) into energy forms desired for end-use demand. The model has sub-national supply and consuming regions. It requires as input the cost and efficiency attributes of existing and new technologies, end-use demands, and supply functions for the primary energy resources; it determines the quantities and prices of energy in intermediate and final delivered forms. The model has been used extensively in support of the Inter-Agency Task Force on Synthetic Fuels.[3]

---

[1] SRI-Gulf Energy Model: Overview of Methodology, E.J. Cazelet (Stanford Research Institute, Menlo Park, California, 1975). The development of the SRI model was supported by Gulf, which is continuing to develop and utilize the model independently of SRI.

[2] Brookhaven Energy System Optimization Model (Associated Universities, Inc. Upton, New York, 1974), E.A. Cherniavsky, Brookhaven National Laboratory Topical Report No. BNL-19569.

[3] "Recommendations for a Synthetic Fuels Commercialization Program," Synfuels Inter-Agency Task Force (Government Printing Office, Washington, D.C., November, 1975). Four Volumes.

The Brookhaven Energy System Optimization Model (BESOM), is an explicit optimization model which also includes a network representation of the energy system, describing the intermediate processing and conversion activities between extraction of primary energy supplies and delivery of final energy forms. The model is national in scope and requires input data on end-use demands, the primary supplies available, and the characterization of the intermediate processing and conversion technology costs and efficiencies. The model uses this information to determine the least-cost combination of existing and new energy technologies required to satisfy end-use demands, consistent with environmental restrictions included as constraints in the model.

Both the SRI-Gulf and Brookhaven models are valuable tools for conditional analysis of technology choice. Two crucial problems are not addressed by either of these modelling efforts however. First, we would expect that the actual commercial availability of a new technology will depend critically on market factors. As we have emphasized, the process of technological change can be viewed as a series of investments. If these investments are made by industry, then they are very much dependent on expectations of future market circumstances.

Thus, a model which purports to explain the penetration of new technologies must also explain the evolution of events which lead to the "availability" of those technologies at a point in time. None of the existing analyses come close to doing this. This is an extremely important (and difficult) research issue.

A second, and closely related, issue concerns the demand for these new technologies. Simple models of consumer behavior based upon simple cost considerations are probably not adequate to characterize consumer response to a new product or technology. A more reasonable approach would be to consider expected consumer reaction to the attributes of new technologies, based upon observing their response to these attributes in existing technologies. The problem is essentially one of using information on consumer response to existing technologies to project reactions to technologies and products not yet observed. The issue of consumer demand for new technologies is not addressed in the SRI-Gulf and Brookhaven models, nor by any other models of energy technology choice with which we are familiar.[1]

5.3.3 Estimation of Industry Activity in the Absence of Government Intervention

As illustrated by Case 4, the benefits of a government program at the point of commerical introduction depends on the likely events that would take place if there were no intervention. It may be, as assumed in Case 1 that nothing would happen without government subsidy. On the other hand, it may be that government subsidy only substitutes for industry investment that would take place in any case, or that it only speeds up the introduction process by a period of a few months or a year or two. In such a case, precious public resources are being devoted to a low-value project. In order to analyze any particular proposal, or to compare proposals, it is necessary to have some understanding of what may take place without intervention, and this once again leads to a need for a clearer understanding of the nature of the market process, how it fails, and how one might gather information about likely industry involvement at the introduction stage.

---

[1] A third deficiency is that demands for energy services are assumed by the model to be inelastic with price.

5.3.4 Estimation of the Likely Effect of a Commercial Demonstration

The next key link in the evaluation process is between the introduction investment given some ex ante appreciation of likely costs $G^i[C(x)]$ and the resulting information after the introduction has been tried, $G^d[C(x)]$. One may be able to develop methods for forecasting the rate of market diffusion given assumptions about the cost of the technology, as discussed in Subsection 5.3.2, but analysis of any particular scheme requires some way to make a link between current expected costs, the government subsidy in commercial demonstration, and the cost inputs that one would put into such a model for forecasting diffusion.

5.3.5 Estimation of the Differential Costs and Effects of Alternative Instruments

As discussed in Section 4.4, the alternative instruments used by the government to subsidize the introduction stage may have very different costs. A fact not discussed earlier is that different instruments may have different effects on the amount of learning that takes place in the introduction stage. In order to choose among the different types of programs discussed in Section 4, one needs to be able to distinguish between the different instruments and their ability to produce a good measure of $G^d[C(x)]$.

The problem of estimating the costs of various government incentives can be illustrated by again turning to the loan guarantee. The cost of a loan guarantee (i.e., the dollar value of the subsidy provided) is the difference between (1) the market value of the debt claim with the guarantee and (2) what the claim's market value would be if the guarantee were removed. Estimating the cost is not difficult if the debt would be a high-grade issue absent the guarantee. But in such cases the cost is probably small--that is, the loan guarantee is unlikely to provide a subtantial subsidy--and therefore is not likely to have much impact.

Loan guarantees are effective subsidies only when the unguaranteed debt has a high probability of default. ("High" is measured relative to the default probabilities normally incurred by private lenders.) But the higher the likelihood of default, the harder it will be to find an existing debt issue that is (1) actively traded and (2) a close substitute for the guaranteed bond in all aspects except the guarantee. The only candidates will bonds of firms which are already in financial distress. It would be difficult to find any existing traded bonds which would be close substitutes for unguaranteed debt secured by, say, a shale oil facility, with a 50 percent ratio of debt to total capitalization.

There is a methodology for evaluating risky debt claims that does not require observing the prices of substitutes.[1] It states that the difference between a debt claim's guaranteed and unguaranteed values is a positive function of the actual present value of the assets standing behind the debt, the

[1] The methodology is an extension of the option-pricing formula developed by Black and Scholes ("The Pricing of Options and Corporate Liabilities," F. Black and M. Scholes, Journal of Political Economy, May-June, 1974, 637-50). There is an article published by Merton applying the methodology to value relatively simple debt claims ("On the Pricing of Corporate Debt: The Risk Structure of Interest Rates," R.C. Merton, Journal of Finance, May, 1974, 449-70). Other work (as yet unpublished) indicates that the approach gives reasonable estimates of the value of actual risky debt claims.

An alternative approach is to use information available (from solicitations or from calculations) on the price guarantees which would be demanded for a given commercial demonstration with and without loan guarantees and then estimate the value of the guarantee as the net present value of the difference in revenue streams to the firms. This method and that discussed above are utilized in Appendix A.

degree of uncertainty about the assets' future value, the maturity of the debt claim, the provisions of the indenture (coupon payments, repayment schedules, etc.) and the current time value of money. The theory's advantage is that it provides a rigorous basis for calculating the value of the guarantee.

One difficulty with this theory is that it assumes that the value of the firms' assets--the value of all its outstanding securities--is independent of the proportions of debt and equity financing. This may not be true, since the existence of risky debt changes the incentives governing operating and investment strategy. This happens regardless of whether the risky debt is guaranteed. Estimating the uncertainty of the assets' future value is a major task as well.

5.3.6 Summary

In Section 5.1 we presented a semi-formal model of government-supported commercialization efforts which summarized the qualitative discussion of Sections 3 and 4. We then (in Section 5.2) built up the key elements of the analysis problem. In Section 5.3 we have addressed the deficiencies in our analytical capabilities. While the general features of the analysis problem are clear, there are important issues where both conceptual development and new analytical tools are required. However, the concepts and tools which are available are sufficient for analyses incorporating many of the key elements of the framework discussed in this paper.