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Government's Role in Energy Technology R&D: A Proposed Model for Strategic Guidance

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DEPARTMENT OF ENERGY

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Energy Division

**GOVERNMENT'S ROLE IN ENERGY TECHNOLOGY R&D:
A PROPOSED MODEL FOR STRATEGIC GUIDANCE**

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April 1996

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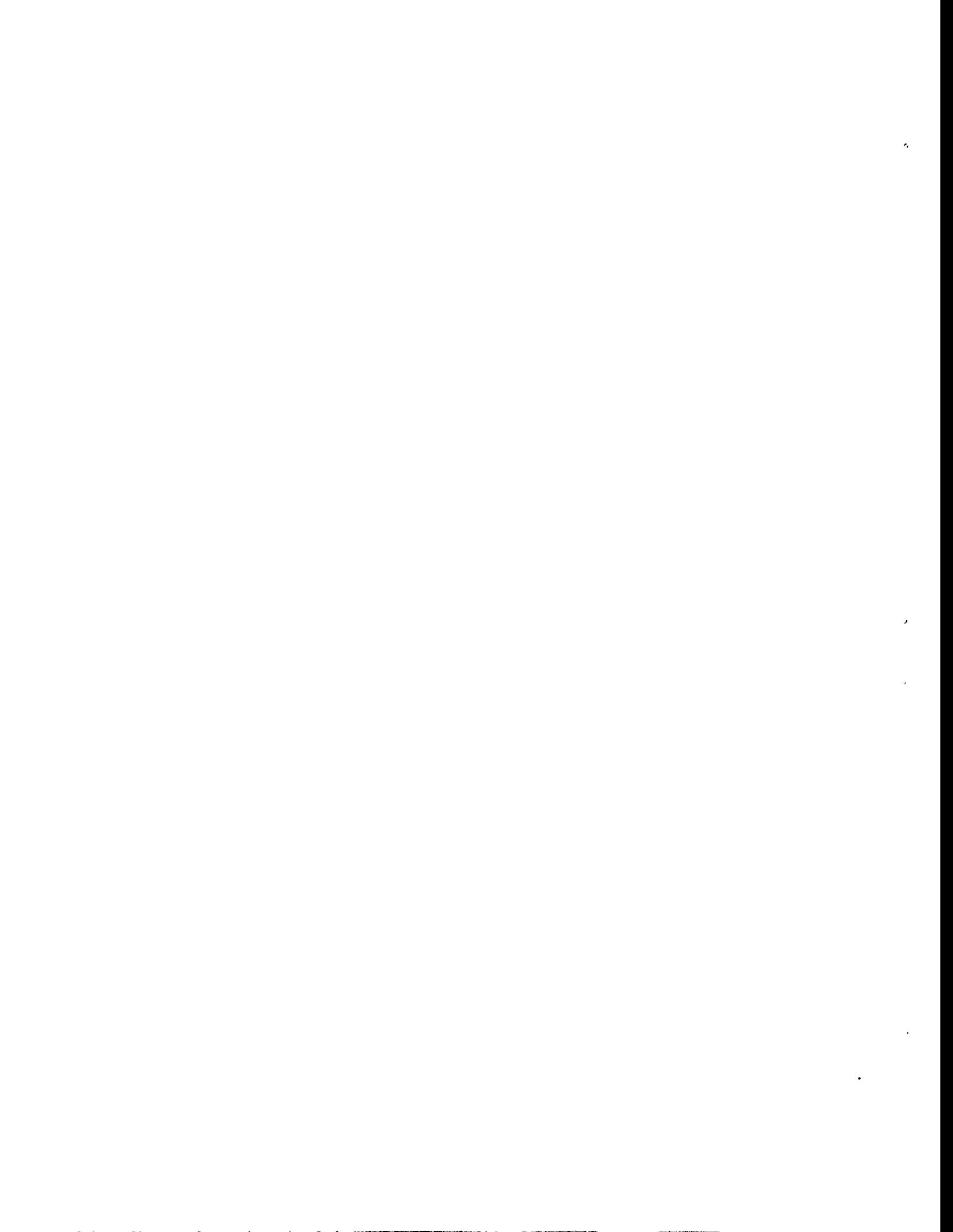
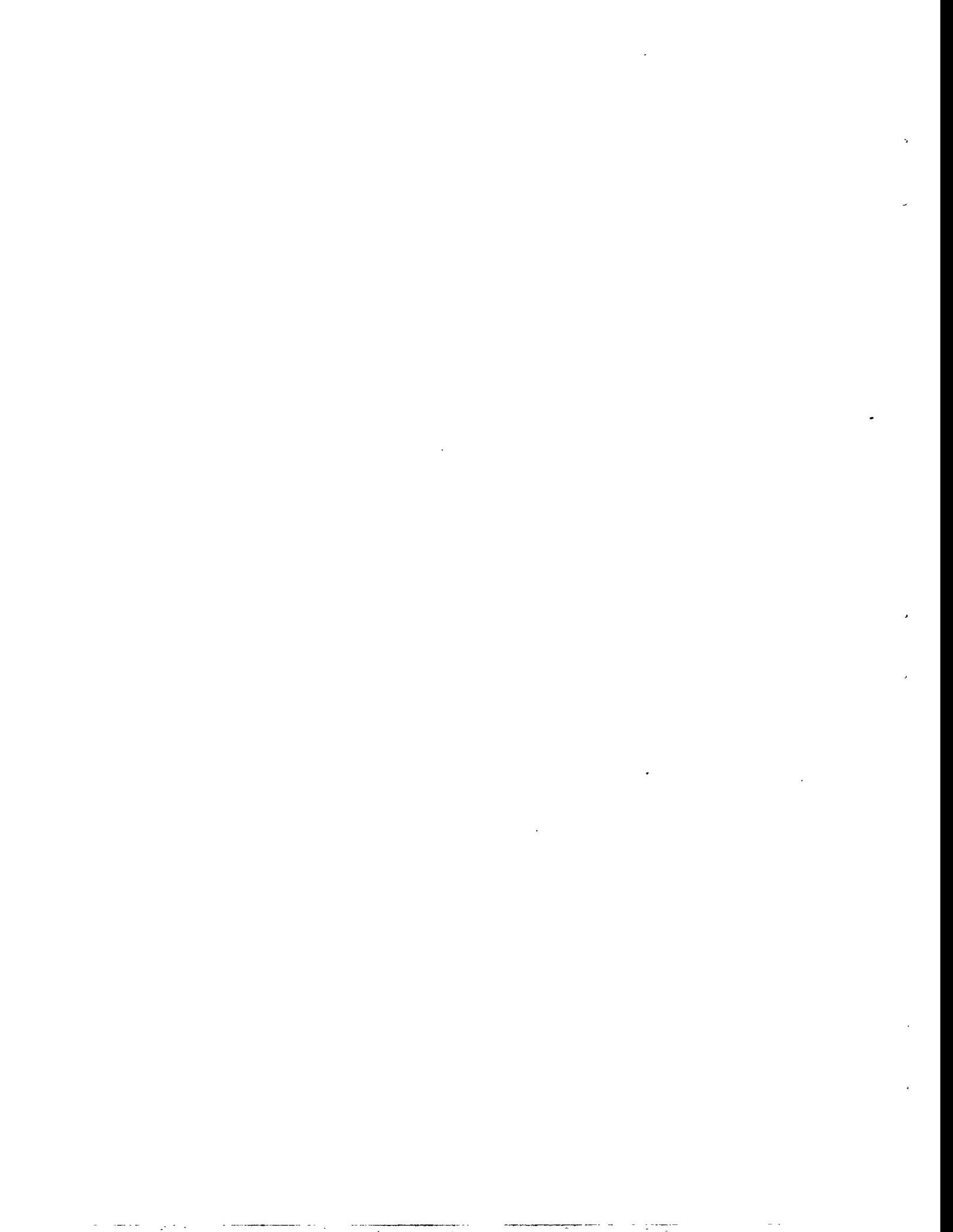


TABLE OF CONTENTS

LIST OF FIGURES	iii
ACKNOWLEDGMENTS	v
ABSTRACT	vii
INTRODUCTION	1
GENERAL TRENDS IN U.S. R&D	2
INTERNATIONAL COMPARISONS OF R&D POLICIES	5
THE LINEAR MODEL OF R&D	8
NEW MODELS OF THE R&D PROCESS	9
IMPLICATIONS OF THE NEW MODEL FOR FEDERAL R&D	11
ELEMENTS OF A DOE ENERGY TECHNOLOGY R&D STRATEGY	12
CONCLUSIONS	15
REFERENCES	17

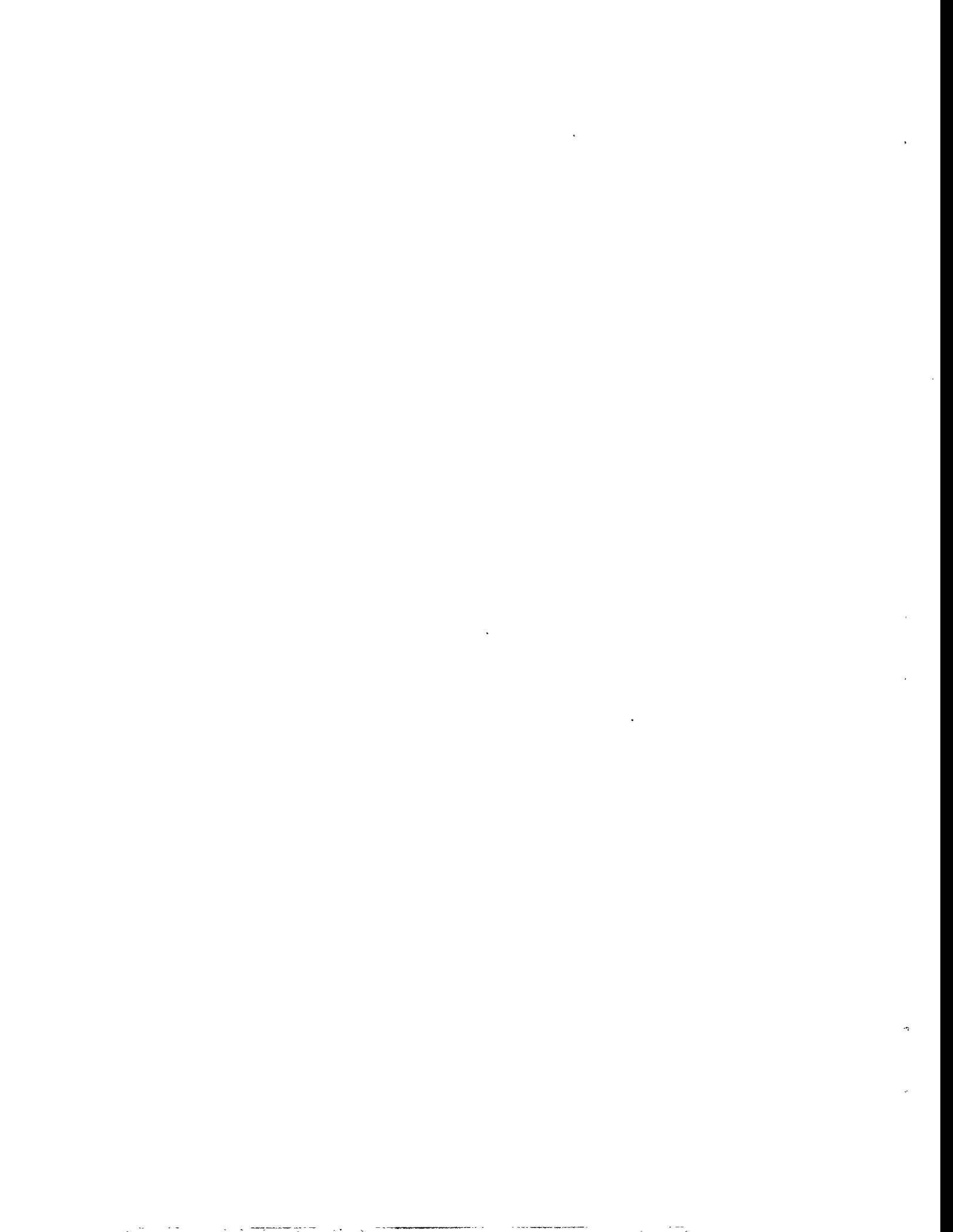
LIST OF FIGURES

Fig. 1. Rates of change in R&D support.	3
Fig. 2. Government support of R&D by objective.	6
Fig. 3. Linear model of innovation.	8
Fig. 4. Chain-linked model of innovation.	11
Fig. 5. DOE energy council model for technology R&D.	14



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ABSTRACT

There is very little argument that the federal government has a clear and important role in the funding of basic research. There is also consensus that the federal government should not fund research that the private sector would do on its own volition. In this paper, we examine the role of government in the “grey” area between these extremes. This area includes generic, crosscutting, and applied technology development and deployment. To provide context for the paper, we first present some general trends in U.S. R&D investment and make international comparisons. These trends clearly show that the amount the U.S. spends on R&D has fallen precipitously since the 1980s. The R&D expenditure data also reveal striking differences in the shares of government R&D allocated to different social objectives between the U.S. and other major industrialized countries. We then review the linear model—the model that characterizes much of the postwar paradigm for U.S. technology policy—and evaluate alternatives to it. These alternative models allow for different types of innovation and explicitly account for feedback from the marketplace and linkages to the private sector, universities, national laboratories. Based on the nonlinear model of innovation, we outline a structure for an R&D technology council that would provide guidance to the U.S. Department of Energy (DOE) on energy technology R&D. The energy technology R&D council would advise DOE on funding priorities for different types of research. Basic research would be conducted at universities and national laboratories as appropriate. Generic technology development would be conducted by teams consisting of national laboratories, the private sector, and universities. The private sector would participate directly in the generic technology development by supplying information and funding. For those activities requiring the development of applied technology, the private sector would cost share in much the same way as is done in the current system with cooperative research and development agreements (CRADAs). Finally, we suggest that economic development councils could be formed to supply additional information and in some cases funding for technology development.

The views expressed in the paper are solely those of the authors and should not be interpreted as representing the U.S. Department of Energy.

INTRODUCTION

There is general agreement that technology has been and will be the key to the health of the U.S. economy. The results of numerous studies have consistently shown that technical change is the single most important factor in contributing to economic growth (Tassey, 1995). These studies generally estimate that technology improvements account from 50% to 85% of economic growth [DOE/Office of Science Policy (PO), 1995]. Moreover, it is estimated that two-thirds to as much as four-fifths of U.S. productivity growth can be attributable to technological innovation (Young, 1988). Further, Boskin and Lau (1992) state that globally, technical progress is by far the most important source of economic growth in industrialized countries. Moreover, as summarized by the Yergin Task Force, many of the industries in which the U.S. enjoys global leadership—aviation, space, electronics, computers, telecommunications, pharmaceuticals, biotechnology, and agriculture—have been driven by substantial and sustained federal R&D spending [DOE/Secretary of Energy Advisory Board (SEAB), 1995a].

While there is little question about the role of technology in the economy, there is a great deal of debate regarding how to bring about technological change and the role of the federal government in research and development (R&D). The current debate regarding the appropriate role of the federal government in R&D is not new, as this issue has been discussed and debated since the early days of the republic (Brooks, 1986). The discussion has been so protracted because there is no clear, definitive answer that emerges from the discussion for important stages (e.g., basic vs product development) of the R&D process. The extremes are clear to all parties. There is little argument about the role of government when the government is the customer for the R&D, for example, in the case of national defense. Also, there is little argument when the role is stated in terms of the truism that the government should undertake socially valuable research that the private sector will not undertake but, at the other extreme, should not do research that the private sector will do on its own. Usually, the principles that emerge are that funding basic research is an appropriate role for the government in the R&D process and that product development that a firm would undertake in its own laboratory with or without government assistance is an inappropriate activity for the government to fund. Put in a slightly different way, it is argued that, in the case of basic research, the social returns greatly exceed the private returns to undertaking the investment, for a number of reasons that will be discussed in greater detail below, and therefore justify government intervention. And in the extreme case where private and social return are the same, and the private firm has the incentive to undertake the optimum amount of investment without the help of government.¹ In fact, in the latter case, government intervention may not only waste the taxpayers' money, but distort the firm's decision-making process and lead to a suboptimum investment from society's perspective.

¹There are many estimates of private and social rates of return. Tassey (1995) has summarized the results of microeconomic studies that estimate the rate of return for investment in R&D at the industry and company level. For the industry level studies, Tassey reports estimates for the innovating firm (private rate of return) and the rate of return for the economy after the innovation has been imitated and adopted by other firms (the spillover or social rate of return). Private rates of return generally range from 20% to 30% with the spillover rate of return in the 50% range. Tassey also presents data that show manufacturing industries that had the highest average annual increases in productivity had the fastest growth rates in output and the fastest growth rates in employment.

While these extremes are clear to everyone, unfortunately there is a large “grey” area in between that is not quite so easily reconciled. This paper will explore this grey area in some detail. While much of the discussion of this issue is economic in nature, it also involves defining the R&D process as it is actually practiced. Since this is crucial to the debate, we will review the traditional understanding of the process—the so-called “linear” model—and evaluate alternatives to it. However, we will begin with a discussion of some of the general trends in R&D in the U.S., some of which are disturbing, and compare them to international trends. The paper will conclude with the implications of the new paradigm of the R&D process for U.S. technology policy.

GENERAL TRENDS IN U.S. R&D

The total amount that the U.S. is expected to spend on R&D in 1995 is about \$171 billion and represents 2.4% of gross domestic product (GDP) (Jankowski, 1995). This is down about 2% from 1994 after accounting for inflation. The proportions of these expenditures represented by basic research, applied research, and development are about 17%, 23%, and 60%, respectively. Of the approximately \$171 billion in total research dollars, industry provides about \$102 billion, and the federal government provides roughly \$61 billion directly. The remainder comes from states, academic institutions, and other nonprofit organizations. The bulk of research performed in the U.S. is done by industry (70%) with academic institutions, the federal government, and other institutions doing 13%, 10%, and 7% respectively. According to Jankowski (1995), academic institutions will increase their share of the total research effort by about 0.4% in 1995, while industry will reduce their efforts by about 1%. Research performed at federal laboratories and research centers will decline by about 5%.

Over the last four decades, the federal government has directly funded more than half of the nation’s total R&D [National Academy of Engineering (NAE), 1993]. However, the trend is noticeably downward. In 1960 the federal government provided about 65% of the national R&D budget; in 1995 the federal share is under 40%. From the early 1960s through the 1970s, the federal government’s share of basic science and engineering research was about 70%. Beginning in 1981, the share remained below 70% and in 1991 dropped below 60%. The historical trends in the federal government’s shares of applied and technology development research are much more pronounced.² These shares have fallen steadily from mid-1960s highs of nearly 60% for development research and

²In this paper, we use the following definitions for basic research, applied research, technology development research. These definitions are from Committee on Criteria for Federal Support of Research and Development (CCFSRD, 1995). *Basic research*—creates new knowledge; is generic, non-appropriable, and openly available; is often done with no specific application in mind; requires a long-term commitment. *Applied research*— uses research methods to address questions with a specific purpose; pays explicit attention to producing knowledge relevant to producing a technology or service; overlaps extensively with basic research; can be short- or long-term. *Technology development*—develops prototypes; uses research findings to develop practical applications; is of general interest to a sector(s), but full returns cannot be captured by any one company; is usually short-term; is not developed for one identifiable product; often makes use of new knowledge from basic and applied research.

nearly 70% for applied research. In 1994, the U.S. share of development research was 35%, and for applied research the share was slightly less than 30%.

Jankowski has examined data that highlight the rates of change in federal government and industry R&D budgets over the last 15 years (Fig. 1). The data in Fig. 1 show high rates of growth in R&D in the first half of the 1980s and substantial declines in the rate of growth in industrial support of R&D in the latter 1980s and into the 1990s. The rate of growth in federal government support turned negative in the mid-1980s and has continued so up to the present. The total decline in the rate of change of R&D spending is attributable to reductions in federal support.

Some argue that the decline in federal R&D is more sobering if one looks at how the current budget is actually allocated. A recent study by the Committee on Criteria for Federal Support of R&D finds that half of the federal spending involves production, maintenance, and upgrading of large-scale weapons and space systems at DOD, NASA, and DOE (CCFSRD, 1995). The activities primarily involve the use of current knowledge and existing technologies, not the creation of new knowledge or the development of new technology. The Committee concludes that the federal R&D budget is misleading because it includes large sums that do not conform to the usual meaning of R&D.

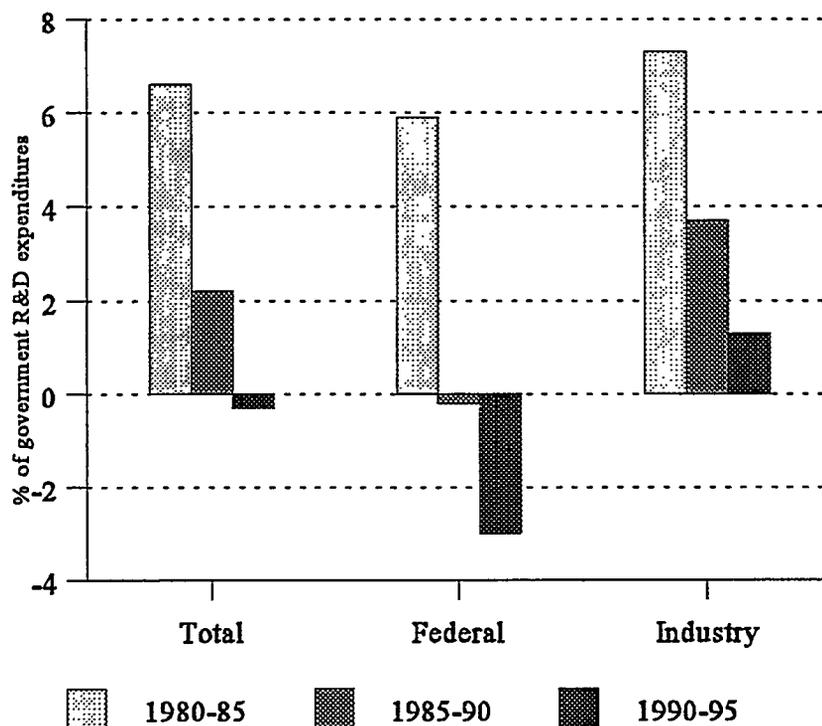


Fig. 1. Rates of change in R&D support.
(Adapted from Jankowski, 1995).

While a more extensive review of international issues will be presented in the next section, it should be pointed out here that R&D growth has been relatively flat worldwide during the 1990s (Jankowski, 1995). In Japan and Germany the ratio of government R&D expenditures to GDP has fallen from 2.9% to 2.7% and from 2.9% to 2.5%, respectively. By comparison, the U.S. R&D/GDP ratio went from 2.8% to 2.4%. Jankowski attributes the declines to economic recession and general government budgetary constraints.

In the energy sector, federal funding for technology R&D has declined nearly 75% in real terms since 1978.³ Real private sector investment in energy R&D also declined 35% since 1984 (DOE/PO, 1995). This decline occurred mostly in the 25 largest energy producers in the U.S. These companies represent over 50% of oil production, over 40% of gas production, and nearly 70% of refining capacity. Currently, companies in the energy and fuel industry spend less than 0.7% of sales on energy R&D (*Business Week*, 1995). Furthermore, the five industries that account for half of U.S. industrial energy use spend less than 1.7% of sales on R&D (DOE/PO, 1995).

One justification for the decline in energy R&D spending is the recent and projected decline in real fuel prices. This, of course, begs the question as to why anyone, especially the federal government, should spend money on energy R&D. One answer might be that the level of fuel prices in no way suggests that we are less susceptible to a future oil price shock. Low oil prices mean greater U.S. oil consumption, diminished U.S. oil production, and expanded reliance on unreliable Persian Gulf oil sources. Without energy R&D to reduce vulnerability these factors could make the U.S. less ready and more susceptible to an oil crisis.⁴ Past experience has shown that an oil price shock can cost the economy trillions of dollars (Greene and Leiby, 1993). Another response might be the near impossibility of reducing U.S. carbon dioxide levels to their 1990 amounts without major R&D efforts to develop and demonstrate cost-effective noncarbon-emitting technologies, such as fission and renewables.

In addition to the trends in R&D funding, considerable change occurred in the competitive position of the U.S. relative to Japan and Western Europe in high-technology and science-intensive trade during the 1970s and 1980s (Tyson, 1992). In the 1980s, foreign governments used technology and industrial policies to promote important domestic industries. This intervention increased the competitiveness of foreign firms in many industries in which the U.S. was once dominant—aircraft, communications, computers, semiconductors, and automobiles. The U.S. lost substantial market

³DOE accounts for over 95% of federal energy research expenditures.

⁴One important trend that could suggest an increasing probability of an oil price shock is OPEC regaining world market share (Leiby, 1996). OPEC market share has grown from 30% to 43% over the past decade (the same as in 1978, the year before the second oil price shock) and is projected to increase to over 50% by the year 2010. Moreover, the rest of the world is drawing down its reserves at twice the rate at which OPEC is producing from its reserves.

share in several high-technology sectors, especially to the Japanese, whose policies focused on process technology and integration of R&D. For example, the Japanese share in world exports of science-based industries more than doubled while the U.S. share declined by about 30%. Industries characterized as being less R&D intensive (i.e., producing products with long product lifecycles and having large economies of scale in production and limited capital mobility) suffered less from foreign competition.

The response to these competitive pressures has been rather dramatic on the part of industry. First, industry has shifted funding away from basic and applied research to activities that support near-term market development and process enhancements. Evidence suggests that the U.S. private sector allocates only 22% of its R&D spending to long-term projects [Office of Technology Assessment, (OTA), 1995]. This compares to 50% in Japan. U.S. industry is downsizing and/or eliminating its own private research labs and is providing smaller contributions to private research institutes, such as the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI) in the energy industry (DOE/PO, 1995). An outcome of this R&D downsizing has been a greater reliance on collaborative R&D in order to reduce costs and spread risks and a greater reliance on R&D performed and/or supported by the federal government.

INTERNATIONAL COMPARISONS OF R&D POLICIES

U.S. science and technology policy is diverse, decentralized, market-oriented, generally disconnected from federal economic policy, and dispersed among numerous federal agencies, state governments, and the private sector. By comparison, the central governments of Japan, Germany, the United Kingdom, and France have clearer responsibilities to support science and technology to serve civilian industrial needs (Lederman, 1994).⁵ Each of these countries has one or more government agencies with a specific responsibility to further industrial science and technology interests.⁶ This support takes the form of using science and technology to develop new processes and products, especially in areas related to international competitiveness—computers, information, biotechnology, robotics, materials, and manufacturing technologies.

⁵The U.S. and these four countries account for about 80% of the world's R&D expenditures.

⁶Japan has a Council for Science and Technology (S&T) in the prime minister's office charged with coordinating, assessing progress, and assigning priorities, as well as a Ministry for International Trade and Industry and Science and Technology Agency. Advisory councils and industry associations work in close cooperation with industry to ensure that government-sponsored R&D is compatible with private sector interests. France has a Ministry of Research and Technology that is responsible for national S&T policy and provides a major part of R&D funding. Germany has a Ministry of Science and Technology, which is the main agency responsible for S&T and provides 70% of government funding. The United Kingdom has a Cabinet Chief Scientific Advisor and staff (similar to the Office of Science and Technology Policy) that provides advice and focus for consideration of S&T priorities and opportunities.

During the 1980s, Japan and European countries emphasized and promoted their high-technology production base, increased R&D funding for industrial production and technology, and created industrial technology development programs (Tyson, 1992; Chiang, 1993). High-tech industries have been given special promotional or protectionist treatment because these governments anticipate a wide array of economic benefits—higher-paying jobs, greater exports, and development of indigenous technological infrastructure. Especially important are the spillover benefits that accrue to other industries. Lederman notes that the more-direct policies of these countries are explained in part by their smaller economies, resource constraints, smaller domestic markets, and the higher proportion of their GNP devoted to exports. In addition, Japan, Germany, the United Kingdom, and France routinely assess and evaluate the effectiveness and results of their government-sponsored science and technology activities (Lederman, 1995).

The U.S. spends considerably more in total on R&D than any other country. For example, the U.S. spent \$138 billion (1987\$) in 1992 on R&D, while comparable R&D expenditures, based on purchasing-power-parity exchange rates, were \$57 billion for Japan, \$30 billion for Germany, \$21 billion for France, \$17 billion for the U.K., and \$12 billion for Italy (NSF, 1994). However, the

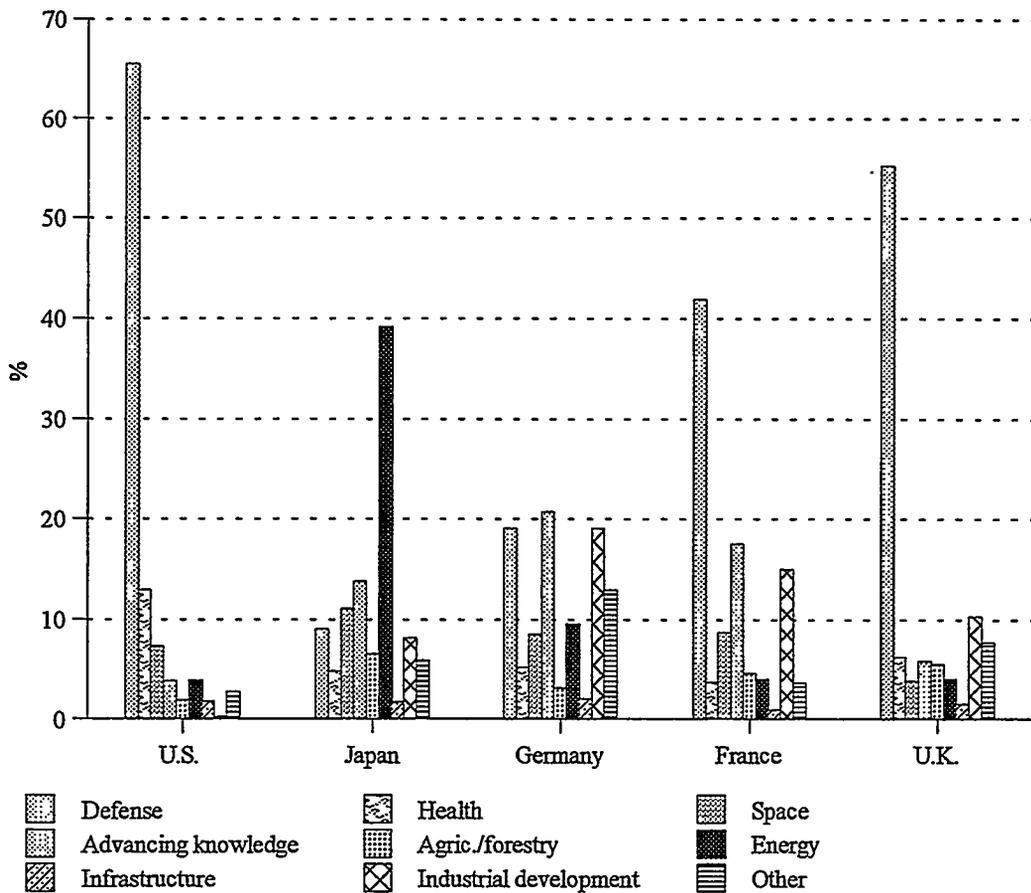


Fig. 2. Government support for R&D by objective.
(Adapted from NAE, 1993)

allocation of R&D expenditures varies greatly between countries. The different focus given to government R&D expenditures between the U.S. and the other major funders of R&D is shown in Fig. 2. This summary shows the shares of government R&D allocated to different social objectives. The data clearly reveal the dominance of U.S. defense expenditures as a percentage of total government support. The United Kingdom and France also spend a relatively high proportion of their R&D budget on defense. Health and space-related R&D accounted for about 20% of the U.S. R&D budget. The remaining objectives, which could be categorized as related to economic development, account for less than 8% of total R&D expenditures (NAE, 1993).⁷ Especially significant in the U.S. is the amount of funding allocated to industrial development, well under 1%. In contrast, Japan spends about 32% of its R&D budget on economic development objectives, while Germany, France, and the United Kingdom spend between 19% and 23% (NAE, 1993). In energy, all countries, but especially Japan and to a lesser extent Germany, spend relatively more than the U.S.

In looking at primary energy use in these countries, one finds significant reductions in oil consumption as a percentage of total primary energy and much greater use of nuclear power. Higher energy prices and more explicit energy R&D policies not only reduce the proportion of oil in primary energy mixes but also create competitive capabilities and advantages for these countries relative to the U.S. in a host of energy technologies.⁸

These countries (especially Japan) have been much more forward thinking about the potential importance that energy technology may have in the early part of the next century. For example, Japan has a 100-year energy plan (New Earth 21) for creating and marketing worldwide new energy technologies to solve greenhouse gas problems and gaining technical advantage in a new generation of energy technologies. This is a cooperative research plan involving industry, universities, and government. The technology development sequence of the plan has deployment of safe nuclear and renewable energy, followed by carbon dioxide fixation and reutilization technologies, low-energy-using processes, and ultimately, fusion and other sources to displace fossil fuels.

Japan and many of the OECD (Organization for Economic Cooperation and Development) countries recognize that funding of energy technology provides dual benefits: (1) improving energy security and the environment and (2) creating markets for energy technology. Efforts to develop new technologies and the development of close relationships between the private sector and government

⁷Infrastructure includes the development of engineering methods, compilation and validation of technical data, development and characterization of materials, measurement and instrumentation and manufacturing process. These are generic technologies applicable to wide range of activities. Environmental and transportation research are main components of "other."

⁸Engi and Icerman (1995) report that France developed significant nuclear energy capability (spent 88% of energy R&D budget on nuclear energy) and developed commercial energy technology capabilities in fluidized-bed combustion, fuel cells, and gas turbines for combined cycles. Japan developed strong capabilities in nuclear power (70% of energy R&D devoted to nuclear), fuel cells, advanced coal technology, and photovoltaics. Most important for Japan was putting in place a comprehensive infrastructure to couple public and private industrial technology initiatives for international markets. Germany developed significant capabilities in combustion and fuel cell technology, coal gasification, and combined-cycle power plants.

have made these countries more substantial competitors in the global market for emerging energy technology and sizable threats to the historical dominance of the U.S. in world energy-technology markets (Frey et al. 1995).

General trends in international energy markets, especially those of developing countries, support the adoption of energy technologies, such as decentralized power-generating equipment, combined-cycle turbines, fuel cells, renewable technology, and cogeneration equipment. These are technologies in which the U.S. risks loss of leadership. It is estimated that the market for energy technology in the developing world alone could reach \$1 trillion annually in the next 20 years (Frey et al. 1995). Currently, the world market for energy-efficiency goods and services is \$84 billion annually (DOE, 1995). General trends likely to influence emerging energy-technology markets include:

- transition of many centrally planned economies to market-based economies,
- continued high population and economic growth in developing countries,
- greater acknowledgment of explicit linkages between energy use and the environment,
- recognition that potential environmental problems such as global warming require the deployment of advanced generation and end-use technologies that are more efficient and less expensive, and
- the expansion of energy consumption in the developing and re-industrializing countries much faster than in the U.S. and other industrialized countries (6.6% annual growth in developing countries, less than 2% in the U.S.).⁹

Clearly, the U.S. has a strategic interest in obtaining a significant share of this market for energy supply, end-use, and environmental control and mitigation technologies. As the rest of the world has recognized, especially the Japanese, energy technologies have not only security and environmental benefits, but also potentially important economic benefits.

THE LINEAR MODEL OF R&D

Since 1945, U.S. R&D policy has been based on what has come to be known as the linear model. The linear model of innovation assumes that basic research is the first and crucial step leading to the commercialization and diffusion of new technology in the marketplace (Tornatsky and Lemer, 1992). Ideas primarily originate in basic research, are transferred to applied research and development, and then go on to production and marketing. These stages and linkages within the model are shown in Fig. 3. Although the linear model of innovation accepts some market information about needs and opportunities in driving basic research, the model generally presumes a one-way flow of ideas from

⁹Energy consumption in the developing world has grown by nearly 50% over the past decade, compared to a 14% increase in the developed world [World Energy Council Commission (WECC), 1993].

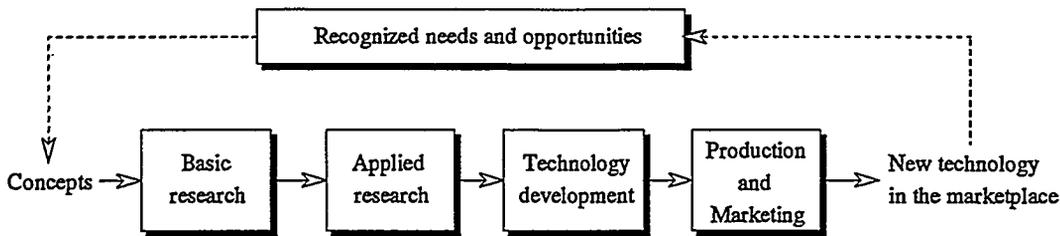


Fig. 3. Linear model of innovation.

basic research to the market. The model also generally presumes that progress comes in great steps with breakthrough innovations creating new industries or transforming existing ones (Panel, 1992).

The linear model of innovation was given legitimacy by Vannevar Bush and as already mentioned became the postwar paradigm for U.S. technology policy. This policy had two parts: the support and funding of basic research and the active development of advanced technology in pursuit of national goals and statutory missions of federal agencies—national defense, space, and health care (Branscomb, 1993). The funding of the basic science component was considered to be a role for government since the private sector either could not afford to undertake the research on its own or would be reluctant to because it could not internalize the full economic benefits from the research or because of the inherently greater risk associated with basic research. Basic research was also considered a public good, especially when coupled with higher education, because it could lead through a sequential process of innovation to the creation of new technologies and new industries. The stages of the linear innovation model downstream of basic research were considered the domain of industry. Industry had the responsibility for responding to the market and tapping into government sources of science and spinoff technology (Branscomb, 1993). Government explicitly refrained from engaging in research to create technology specifically for commercial exploitation.¹⁰

This model gained considerable acceptance because it fit much of the mission-oriented research of the Cold War period—defense technologies and commercially valuable spinoffs (semiconductors, computers, aircraft, etc.). The model also conformed well to a number of economically important, but simple, technologies—petrochemicals, drugs and medicines, and some industrial components (Rycroft and Kash, 1994a). Indeed, this technology-push model became the basis for many of the technology transfer programs implemented by federal agencies (Panel, 1992).

NEW MODELS OF THE R&D PROCESS

Recent trends in R&D funding and the fact that the U.S. no longer leads in many key technology areas have raised serious doubts about the adequacy of the linear model and its general policy implications for technology. Many now argue that the linear model of innovation that has government playing largely a funding role in basic research is no longer appropriate for many of the

¹⁰There are some notable exceptions in agriculture and health care.

new and emerging technologies that are likely to be important to economic growth (Kline and Rosenberg, 1986; Ziman, 1991; OTA, 1995). The model is inapplicable to the way industries compete through rapid incremental progress in the 1990s because most commercial innovations are driven by market opportunity, not scientific discovery (Branscomb, 1993). Bloch also concludes that government policy making, for the most part, is outdated because it relies on the linear model of innovation—a model that does not describe today's realities or needs (Bloch, 1994). He argues that science and technology have an interactive and interdependent relationship that is anything but linear and that the boundary between the government (basic research) and the private sector (innovation and technology development) no longer exists.

Some authors state that, in general, the linear model does not adequately account for the fact that many innovations come not from basic research but from exploiting existing research, perceiving changes in market demand, and recognizing the potential for new processes and products.¹¹ Further, innovation does not necessarily follow a linear path. Developments in technology can often precede research, and learning during production and marketing can provide valuable feedback by stimulating new ideas and generating new science. For example, Kline and Rosenberg (1986) point out that much of the pressure to develop new materials is a direct result of feedback on problems encountered in creating technologies and products such as turbines, engines, and photovoltaic cells.

In another line of reasoning, Rycroft and Kash (1994a) show that there is an ongoing trend toward increasing technological complexity, and for this situation they conclude that the linear model does not fit very well. The trend is away from mass-produced commodities to high-value-added products and processes that can be adapted quickly in response to changing market conditions.¹² Technologies have evolved from having a few components and architectures connected in a simple, linear fashion to technologies that are now much more integrated and composed of many subsystems and architectures. For complex technologies, users, suppliers, and assemblers need to be linked directly to manufacturers, product designers, and those engaged in both basic and applied research (Rycroft and Kash, 1994a).

Many alternative descriptions of this nonlinear model have been proposed to reflect the interactions of researchers and users of research (Tornatsky and Lemer, 1992). For example, the chain-linked model focuses more on the potential market demand as a source of innovation (Fig. 4). In this model, research is an ongoing stream of activity in parallel with product and process development, production, and marketing (Tornatsky and Lemer, 1992). Research contributes to all stages of the

¹¹This is an area in which the Japanese excel. Japan has great strengths in learning and adapting commercial technology adopted abroad (OTA, 1994).

¹²Rycroft and Kash (1994a) examined the 30 most valuable product technologies internationally traded in 1970 and 1990. Their results show (1) that only about 75% of the most valuable technologies for 1970 are listed for 1990 and (2) that both the complexity of technologies and the proportion of the total value represented by complex technologies increased substantially over the 20-year period. They estimate that about 75% of the most valued products in the world could be characterized as complex.

process (Kline and Rosenberg, 1986). As Kline and Rosenberg state, this improved model indicates not one but five major pathways all of which are important to the innovation process:

- the numerous feedbacks that link and coordinate R&D production and marketing,
- the side-links to research along the central line,
- the long-range generic research for innovation backup,
- the creation of wholly new products and processes from research, and
- the essential support of science itself from the products and processes of innovation activities.

The chain-linked description of the nonlinear process allows for three different types of innovation: science- or technology driven innovation, market-driven innovation, and incremental innovation (OTA, 1995). Other descriptions, such as the “concurrent” and “composite,” also reflect the explicit feedback missing in the linear model of innovation and the linkages with other firms, universities, government laboratories, and the marketplace. All of these descriptions of the nonlinear models of innovation reflect the dynamic process that is missing in the linear model (Rycroft and Kash, 1994a).

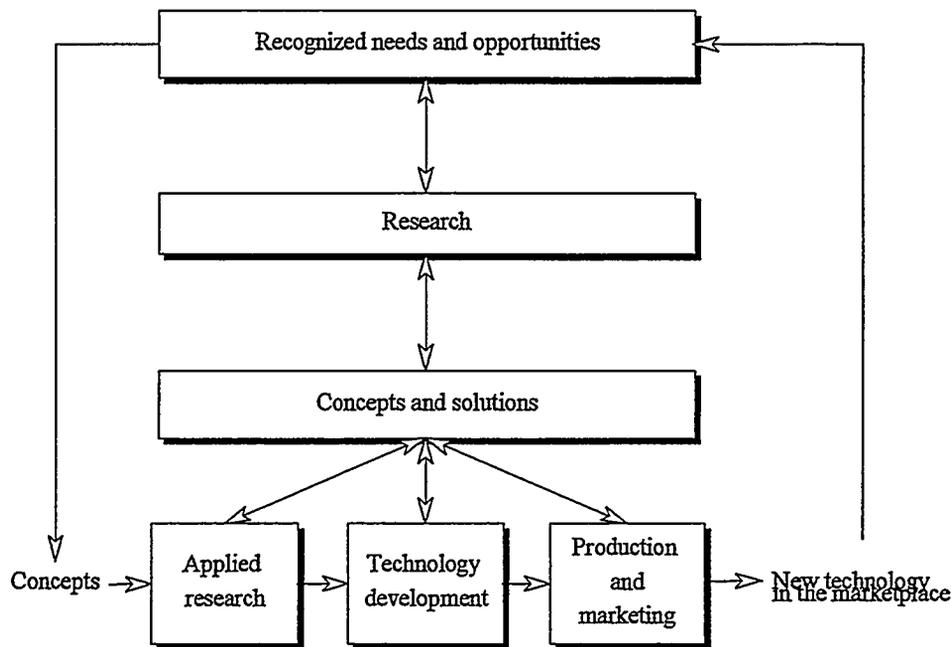


Fig. 4. Chain-linked model of innovation. Originally proposed by Kline and Rosenberg (1986), adapted here from Tornatsky and Lerner (1992).

IMPLICATIONS OF THE NEW MODEL FOR FEDERAL R&D

The ability of a nation to capitalize on new technology developments depends on its system of innovation (OTA, 1995). There are strong arguments for abandoning the linear model that has been used as the basic paradigm for much of the R&D conducted in the U.S. Similar arguments have also been made by the Yergin Task Force on strategic energy R&D (DOE/SEAB, 1995a). The new paradigm for innovation recognizes the importance of feedback, interactions, and multiple pathways to innovation and the commercialization of new technology. The challenge is to design a federal strategy that successfully promotes innovation in the most valuable technologies and products (Rycroft and Kash, 1994a). This strategy would entail new collaborative arrangements and organizations, more direct linkages and feedback, the development of an appropriate institutional infrastructure, and an ongoing process of R&D evaluation. The elements of such a strategy were discussed by the Panel on the Government Role in Civilian Technology (Panel, 1992), the Yergin Task Force (DOE/SEAB, 1995b), and most recently the OTA (1995).

The federal government clearly has a role and responsibility in defining the rules, regulations, and laws that affect the private sector's ability to innovate (e.g., changes in antitrust laws, use of CRADAs to enhance collaboration). It should also include activities that serve to reduce uncertainty and to promote new market (e.g., changes in regulatory processes or greater involvement in the testing, demonstration, and verification of technology). The federal government can play an important role in defining relevant technology standards in emerging technologies. The federal government can also help alleviate private sector concerns about opportunistic behavior that often increases transaction costs, such as defining legal frameworks for cooperation (defining property rights and having contract laws and agreements in place of those that serve to limit negotiation) and through administrative action (e.g., monitoring of collaborations and enforcement with reprisal for violation). All of these actions can help lower the costs and risks of doing R&D.

The federal government has a legitimate role in fostering networks and linkages among those engaged in new product or process development by lowering costs, helping to spread risks, and promoting and developing markets for new technology. This can be accomplished in several ways, for example, through government procurement to stimulate and develop markets, tax and credit policies to help attain important social objectives (e.g., enhanced security, improved environmental protection), and other special development programs (e.g., export promotion of technology).

However, the implications of the nonlinear model go well beyond these activities. The message of the nonlinear model is not simply that the federal government has a strong role in directly funding R&D beyond the narrow boundary of basic research, but rather that the organizational aspects of the research must be rethought. We must create structures that bring together the relevant elements of the research community to address critical technology needs of the nation in an integrated way. The context of the funding is as important as the funding itself, and we must provide the funding so that it enhances the interactions of the relevant research actors in meaningful ways. To fund the pieces separately without creating the structure fails to optimize the expenditure of the R&D dollars as

surely as not funding any single element. In other words, we must create the relevant feedback loops in our research institutions. There is no single way to do this, but the next section suggests the elements of such an organization for the DOE.

ELEMENTS OF A DOE ENERGY TECHNOLOGY R&D STRATEGY

The DOE is perhaps uniquely positioned to implement a science and technology research and development program based on the nonlinear model of innovation. Some steps have been taken to implement some aspects of the new paradigm. For example, DOE has played a prominent role in the use of CRADAs (Cooperative Research and Development Agreements) to develop new technology important to U.S. economic growth, and in the development of technology standards. National user facilities are also available to U.S. manufacturers to test new products and to verify performance claims. However, a bolder approach to fostering new energy technology development is called for if the U.S. is to remain a world leader in energy technology and to capitalize on a world market that offers enormous potential for exports. The DOE's major missions for energy R&D—energy security, environmental quality, and scientific and technical leadership—all call for an active program that will not only bring direct benefits to the U.S. in the form of reduced risks from a major oil supply disruption and a cleaner environment, but also provide increased opportunities for exports to a world energy technology market that is growing more rapidly than perhaps any other, save information and communication technology.

The DOE currently has major R&D programs with universities, national laboratories, and private companies. However, many of these programs could benefit from greater integration to capitalize on the strengths of the respective entities and more fully capture the potential benefits to the R&D. At the risk of oversimplifying, the relative, but not exclusive, strengths of the three types of organizations might be summarized as basic, disciplinary research by universities; multidisciplinary problem solving, prototyping, and testing with unique facilities by national laboratories; and product development and deployment by private companies. With the appropriate structure, the three can work as a coordinated team, driven by market forces as perceived by the private companies, but with all three actively benefiting by the interaction in a way that no single entity could alone.

All types of institutions provide a constant source of creative ideas, many of which are easily and rapidly deployed into the marketplace. However, many of the ideas require development and testing at specialized facilities that are available only at a limited number of institutions. In this age of constrained resources, there are strong arguments for not duplicating these facilities and for capturing economies of scale at a single facility. While the private sector has the ultimate task of transforming the research into socially valuable products for the market in this model, the private sector is not only a user of the R&D, but is an active participant in the process, providing innovative ideas, unique facilities in some cases, and valuable production and market experience.

The DOE could implement this structure by creating an R&D technology council to provide strategic guidance to DOE regarding energy technology R&D. The council could have active subgroups focused on a particular set of technologies, such as fossil or energy efficiency. However, the council should have a broad mandate to look across all technologies. As shown in Fig. 5, membership on the council would include representatives from universities, national laboratories, and the private sector. The council would rank potential development activities and advise the DOE on funding priorities for basic research, generic and crosscutting technologies, infrastructure, and personnel matters. This model requires a much greater than present movement of people between institutions to capture the strengths of respective partners. The DOE would provide funding and information through a task force set-up for the specific technology R&D activity. The task force would include representatives from the private sector, national laboratories, and universities who will be engaged in the specific R&D activity. A supporting national laboratory would serve specific task forces based on the program needs.¹³ Basic research would be conducted at universities and national laboratories as appropriate in support of the task forces. Generic and crosscutting technology development would be conducted by teams coordinated by a national laboratory, but scientifically led by a technology task force. Depending on the specific technology or technology areas, the teams would consist of researchers from universities, national laboratories, and the private sector. For those activities requiring development of applied technology or activities in which the product is close to development, the private sector would cost share in much the same way as is done in the current system with CRADAs or undertake the research in its own facilities. Finally, economic development councils would be formed to supply additional information and, in some cases, funding for infrastructure development. The economic development councils would have representatives from state and local governments as well as other stakeholder groups that have a specific interest in the activity. The economic development councils are viewed as having a primary interest in the areas of technology deployment and local and regional development. Fig. 5 also indicates the primary areas of fiscal responsibilities for each of the major participants.

CONCLUSIONS

Changes in the nature of technology (e.g., increased complexity and innovation networks) have made collaboration essential to success (Rycroft and Kash, 1994b). The success of the Japanese in gaining world leadership in a number of emerging technologies attests to the need to develop R&D policies that are more in tune with nonlinear models of innovation that explicitly acknowledge feedback and disregard the public-private sector distinction. Greater collaboration between the public and private

¹³Although the national laboratories serve as the supporting institution for the R&D task forces pictured in Fig. 5, other entities could fill this role as well.

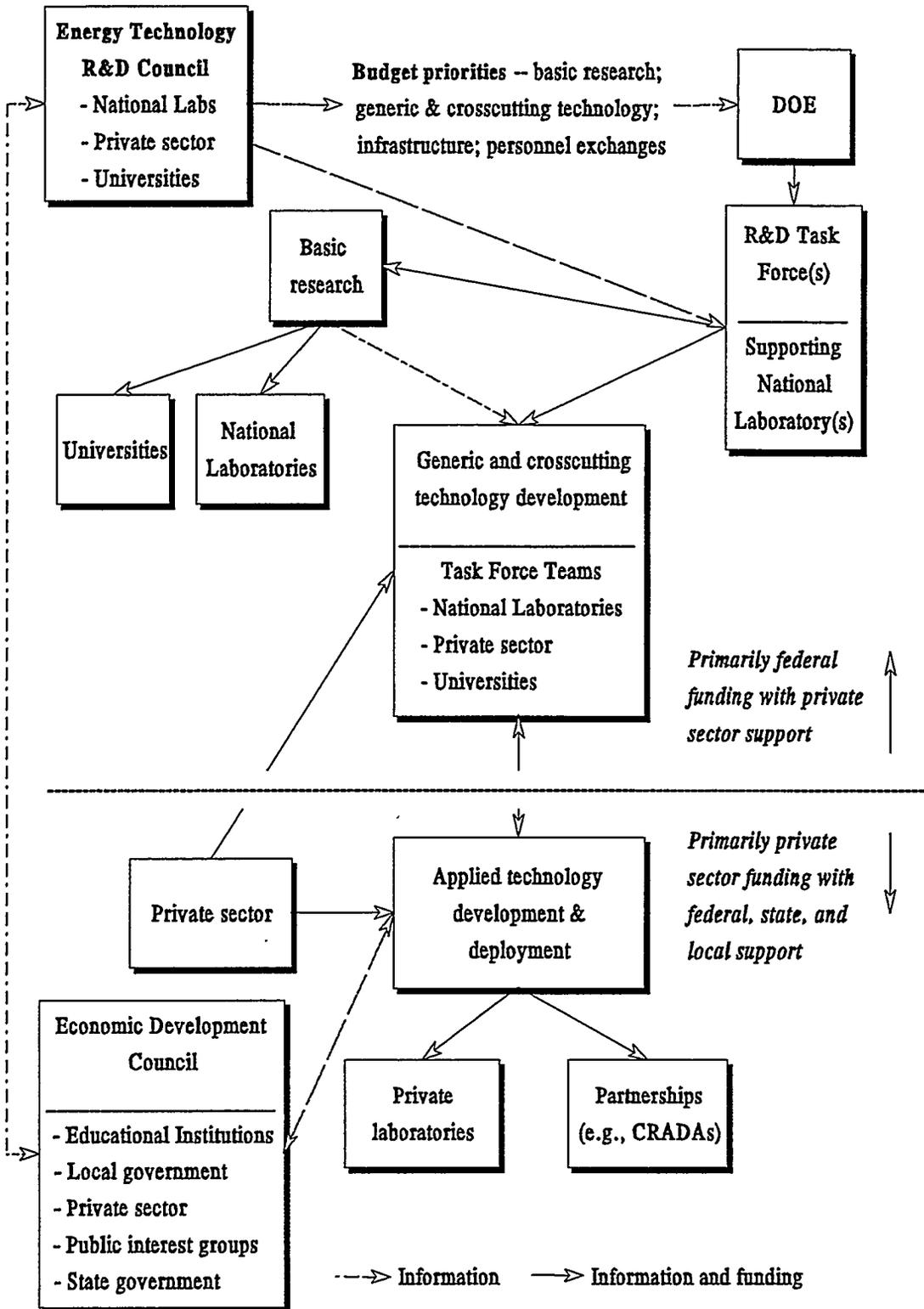


Fig. 5. DOE energy council model for technology R&D.

sectors in doing research offers numerous advantages to both the government, in meeting social objectives, and to individual firms.¹⁴

Until the limited technology policy initiatives of the 1980s and 1990s, the official U.S. policy was to reject outright overt collaboration with industry. There are extreme voices, such as those at the Cato Institute, who still argue against all ties between the government and the private sector (Moore and Stansel, 1995). Critics of technology policies contend that the federal government has a poor track record in picking industrial winners and losers and that purported economic benefits fail to materialize. More specifically, the critics argue that the choice of technologies for R&D should be market driven and the best judge of this is the private sector. However, the model outlined above involves the private sector at important points in the decision making process, both at the generic and later stages of the development process. The model brings together critical elements of the R&D community to capture the strengths of the respective institutions in the R&D process—it combines basic, applied, and unique facilities in a development process that permits feedback mechanisms to operate and permits flexibility in funding as the technology moves closer to the marketplace. The argument that involving the private sector in this activity amounts to corporate welfare is to entirely miss the point of the nonlinear model. If the appropriate R&D structure is in place, and efficient methods of cost sharing are instituted, the term “government welfare” is as appropriate as the term “corporate welfare.”

Furthermore, Rycroft and Kash (1994b) remind us that the U.S. has had long-standing policies and programs in place to support commercial technology development in defense, agriculture, and health care. These policies were justified on the basis of national security in the case of defense industries and on the basis of political pressure in the case of agriculture and health care. In all three of these areas, the government plays a direct role by (1) underwriting risk and fronting the bill for R&D costs, (2) acting as broker to link industry, universities, and government, and (3) manipulating the market to create demand for the technological innovations (Rycroft and Kash, 1994b). We should remember that the U.S. is a world technology leader in these three industries and that the technologies developed in these industries are a source of large trade surpluses.

¹⁴Specific benefits to the private sector would include economies of scale and scope in research, joint financing of expensive R&D efforts that have important spillover benefits, avoidance of R&D duplication, spreading risks, gaining access to new areas and new research networks, taking advantage of mutually complementary positions, and internalizing externalities created by R&D spillovers (Tripsas et al. 1995).

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