# Analysis of Federal Expenditures for Energy Development

September 2008

By
Management Information Services, Inc.
Washington, D.C.

Prepared for
The Nuclear Energy Institute
Washington, D.C.

## Executive Summary

For decades the federal government has employed a variety of incentives to support research, development and deployment of energy sources. The types, amounts and targets of federal incentives have changed substantially over time, making it difficult to follow where these expenditures have gone and what they have done for the nation's energy supply.

To gain insight into the history of energy incentives, the Nuclear Energy Institute (NEI) asked Management Information Services Inc. (MISI) to prepare an independent assessment. The findings provide a quantitative compilation of the amounts and types of incentives provided from 1950 to 2006 and the energy sources targeted with each type of incentive. As summarized in Exhibit 1 below, the findings indicate that the largest beneficiaries of federal energy incentives have been oil and gas, receiving more than half of all incentives provided since 1950. The federal government's primary support for nuclear energy development has been in the form of research and development (R&D) programs, one of the more visible types of incentives identified. Over the last decade (since 1997), federal spending on R&D for coal and renewables has exceeded spending on nuclear energy R&D.

### Exhibit 1 – Summary of Federal Energy Incentives, 1950–2006

**(Billions of 2006 Dollars[1])**

| TYPE OF INCENTIVE | ENERGY SOURCE | | | | | | | SUMMARY FOR INCENTIVE TYPE | |
|---|---|---|---|---|---|---|---|---|---|
| | Oil | Nat. Gas | Coal | Hydro | Nuclear | Renew-able[2] | Geo-thermal | Total | Share |
| **Tax Policy** | 173 | 88 | 31 | 12 | | 20 | 2 | 326 | 45% |
| **Regulation** | 116 | 3 | 7 | 5 | 11 | | | 142 | 20% |
| **R&D** | 7 | 6 | 32 | 1 | 67 | 19 | 3 | 135 | 19% |
| **Market Activity** | 5 | 2 | 2 | 59 | | 2 | 2 | 72 | 10% |
| **Gov't Services** | 31 | 1 | 14 | 1 | 1 | 2 | | 50 | 7% |
| **Disbursements** | 3 | | 8 | 2 | -14 | 2 | | 1 | ~0% |
| **Total** | **335** | **100** | **94** | **80** | **65** | **45** | **7** | **726** | |
| **Share** | 46% | 14% | 13% | 11% | 9% | 6% | 1% | | 100% |

[1] All estimates quoted are in constant 2006 dollars, unless otherwise noted, and refer to actual expenditures in the relevant fiscal year, rounded to the nearest billion. Totals and percentages may differ slightly due to independent rounding.

[2] Renewables are primarily wind and solar energy sources.

## About Management Information Services, Inc.

MISI is an internationally recognized, Washington, D.C.-based economic research and management consulting firm with expertise on a wide range of complex issues, including energy, electricity and the environment. The MISI staff offers capabilities in economics, information technology, engineering and finance and includes former senior officials from private industry, federal and state government, and academia.

Over the past two decades, MISI has conducted extensive proprietary research and since 1985 has assisted hundreds of clients, including Fortune 500 companies, nonprofit organizations and foundations, academic and research institutions, and state and federal government agencies including the White House, the U.S. Department of Energy, the U.S. Environmental Protection Agency, the Energy Information Administration, the U.S. Department of Defense, NASA, and the U.S. General Services Administration. In recent years, MISI has analyzed energy incentives for the U.S. Department of Energy and the National Academy of Sciences, among others.

For more information, please visit the MISI Web site at *http://www.misi-net.com*.

## Contents

## Exhibits

# I. Introduction

With concern about the price and availability of energy increasing, public interest in the role of federal incentives in shaping today's energy marketplace and future energy options has risen sharply. That interest has met with frustration in some quarters and half-truths in others because of the difficulty in developing a complete picture of the incentives that influence today's energy options. The difficulty arises from the many forms of incentives, the variety of ways that they are funded, managed and monitored, and changes in the agencies responsible for administering them. It is no simple matter to identify incentives and track them through year-to-year changes in legislation and budgets over the 50-plus years that federal incentives have been a significant part of the modern energy marketplace.

To better understand the history of federal energy expenditures, the Nuclear Energy Institute (NEI) asked Management Information Services, Inc. (MISI) to develop a comprehensive profile of incentives employed as instruments of federal energy policy. MISI's long history of research and publications in energy and economics for the National Academy of Sciences, the U.S. Department of Energy and others assured that MISI would provide the expertise and objectivity necessary to collect and analyze the data required for this independent assessment.

The findings of this study provide a quantitative compilation of the amounts expended from 1950 to 2006, the types of incentives provided and the energy sources targeted with each type of incentive. The findings indicate that the largest beneficiaries of federal energy incentives have been oil and gas, receiving more than half of all incentives provided since 1950. The federal government's primary support for nuclear energy development has been in the form of research and development (R&D) programs, one of the more visible types of incentives identified. In the past 10 years, federal spending on R&D for coal and renewables has exceeded expenditures for nuclear energy R&D.

Section II summarizes the data sources and analytical methods used in this study. Section III describes the six types of incentives identified in this study. Section IV compares the amount expended on incentives for the seven energy sources examined. Section V focuses on expenditures for one of the more visible types of incentives, R&D. Section VI offers conclusions from the study.

## II. Sources and Methods

Information presented in this report was compiled from publicly available budget documents prepared by federal agencies with a role in energy development. The agencies are identified in Appendix 1 and include the U.S. Department of Energy and its predecessors, the U.S. Nuclear Regulatory Commission, the Office of Management and Budget (OMB) and others. The types of documents examined for this study include congressional budget submissions, requests, justifications, revisions and program defenses. Additional information on sources is provided in Appendix 2.

Agency programs included in this study were selected on the basis of the authors' expertise in economic and energy policy analysis. The authors examined program documents and determined the types and amounts of incentives provided by each program. Additional information on programs included in this study is provided in Appendix 3. The authors translated current-year expenditures (nominal dollars) into constant 2006 dollars using price deflators derived from data published by OMB, Congressional Budget Office, and the U.S. Department of Commerce's Bureau of Economic Analysis (BEA). The constant dollar values were then compiled by incentive type and tabulated for presentation. The price deflator values are listed in Appendix 4.

## III. Types of Federal Expenditures on Energy

The federal government has employed a variety of incentives to encourage the development of domestic energy resources. Incentives for energy have taken many forms, including direct subsidies, tax concessions, market support, technology demonstration programs, research and development (R&D) programs, procurement mandates, information generation and dissemination, technology transfer, directed purchases, and government-funded regulations. This analysis aggregates the various incentives into six categories:

- tax policy
- regulation
- research and development
- market activity
- government services
- disbursements.

General characteristics and examples of these six types of incentives are provided below.

### A. Tax Policy

Tax policy includes special exemptions, allowances, deductions, credits, etc., related to the federal tax code. Tax policy has been, by far, the most widely used form of incentive mechanism, accounting for $325 billion (45 percent) of all federal expenditures since 1950. The oil and gas industries, for example, receive percentage depletion and intangible drilling provisions as an incentive for exploration and development. Federal tax credits and deductions also have been utilized to encourage the use of renewable energy.

### B. Regulation

This category encompasses federal mandates and government-funded oversight of, or controls on, businesses employing a specified energy type. Federal regulations are an incentive in the sense that they can contribute to public confidence in, and acceptance of, facilities and devices employing a new or potentially hazardous technology. Federal regulations or mandates also can directly influence the price paid for a particular type of energy. Thus, it is not surprising that federal mandates and regulations have been an important part of energy policy, accounting for $141 billion (20 percent) of energy incentives.

For this analysis, two types of federal expenditures associated with regulation were identified: 1) gains realized by energy businesses when they are exempt from federal requirements that raise costs or limit prices, and 2) costs of federal regulation that are borne by the general budget and not covered by fees charged to the regulated industries.

An example of the first type of regulatory incentive comes from the oil industry, which has benefited from:

- exemption from price controls (during their existence) of oil produced from "stripper wells"
- the two-tier price control system, which was enacted as an incentive for the production of "new" oil the higher-than-average rate of return allowed on oil pipelines.
- The higher-than-average rate of return allowed on oil pipelines.

An example of the second type of regulatory incentive comes from the nuclear energy industry. Through the NRC (and its predecessor, the U.S. Atomic Energy Commission), the federal government regulates the design and operation of nuclear plants to ensure protection of public health and safety. In this case, an independent, credible federal regulatory regime promotes public and investor confidence in commercial nuclear enterprises around the country. The cost of regulating nuclear safety through the NRC/AEC through 2006 was almost $11 billion. This amount includes the cost of administering both agencies (AEC to 1975 and the NRC from 1975 forward) as well as credit for regulatory user fees paid by electric utilities. Since 1991, these user fees have offset most of the NRC's operating budget.

### C. Research and Development

This type of incentive includes federal funding for research, development and demonstration programs. Of the $725 billion in total federal spending on energy since 1950, research and development funding comprised about 19 percent ($136 billion).

### D. Market Activity

This incentive includes direct federal government involvement in the marketplace. Through 2006, federal market activity totaled $72 billion (10 percent of all energy incentives). Most of this market activity was to the benefit of hydroelectric power and, to a much smaller extent, the oil industry.

Market intervention incentives for hydroelectric energy include the prorated costs of federal construction and operation of dams and transmission facilities. These costs are prorated because beginning in the 1930s, federal dams and water resource projects have been multi-purpose. The results of these investments include flood control, navigation, recreation, regional development and other benefits in addition to hydroelectric power. Therefore, it is necessary to estimate the portion of the net investment in construction and operation of dams allocated to power development and the relevant transmission facilities.

Market activity incentives for the oil industry include the relevant planning, leasing, resource management and related activities of the U.S. Department of the Interior's (DOI) Bureau of Land Management (BLM).

### E. Government Services

This category refers to all services traditionally and historically provided by the federal government without direct charge and totaled $51 billion through 2006, representing 7 percent of total incentives. Relevant examples include the oil industry and the coal industry.

U.S. government policy is to provide ports and inland waterways as free public highways. In ports that handle relatively large ships, the needs of oil tankers represent the primary reason for deepening channels. They are usually the deepest draft vessels that use the port and a larger-than-proportional amount of total dredging costs are allocable to them. The authors estimated the expenditures for federal navigation programs and allocated these costs as a petroleum subsidy according to the ratio of petroleum and petroleum-based products carried to all waterborne trade. Similarly, to estimate the incentives for coal production from federal expenditures for ports and waterways, the costs for all improvements were multiplied by coal's share of the tons of total waterborne commerce.

## F. Disbursements

This category involves direct financial subsidies such as grants. Since 1950, direct federal grants and subsidies have played a very small role in energy policy, accounting for $300 million, a negligible fraction of total incentives.

An example of federal disbursements is subsidies for the construction and operating costs of oil tankers. For nuclear energy, federal disbursements are negative, meaning the industry pays more than it receives in disbursements as a result of the contributions the industry makes to the Nuclear Waste Trust Fund. As of 2006, the Nuclear Waste Trust Fund had accumulated a $14 billion surplus. The entry shown in Exhibits 1 and 2 for disbursements to nuclear energy is shown as a negative value to reflect the industry's overpayment compared to what has been disbursed on its behalf.

## IV. Amounts and Recipients of Federal Expenditures

The amounts and recipients of each type of incentive are summarized in Exhibit 2, which shows that:

- The federal government has provided an estimated $725 billion for energy developments since 1950.
- The largest type of incentive has been tax concessions, amounting to about 45 percent of all incentives.
- Federally funded regulation and R&D, at about 20 percent each, are the second and third largest incentives.

### Exhibit 2– Summary of Federal Energy Incentives, 1950–2006

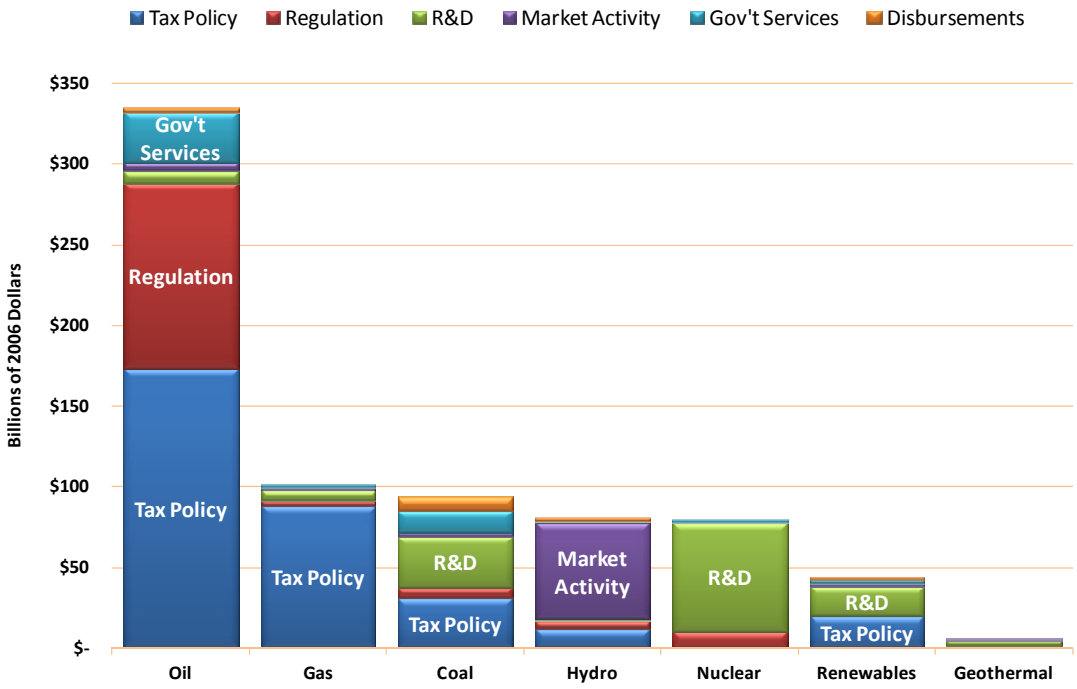
**(Billions of 2006 Dollars[3])**

| TYPE OF INCENTIVE | ENERGY SOURCE | | | | | | | SUMMARY FOR INCENTIVE TYPE | |
|---|---|---|---|---|---|---|---|---|---|
| | Oil | Natural Gas | Coal | Hydro | Nuclear | Renew-ables[4] | Geo-thermal | Total | Share |
| **Tax Policy** | 172.9 | 88.3 | 30.7 | 12.1 | | 19.6 | 1.6 | 325.2 | 45% |
| **Regulation** | 115.6 | 3.3 | 6.9 | 4.7 | 10.9 | | | 141.1 | 20% |
| **Research & Development** | 7.4 | 6.2 | 31.5 | 1.3 | 66.8 | 19.1 | 3.3 | 135.6 | 19% |
| **Market Activity** | 5.1 | 2.0 | 2.3 | 59.3 | | 1.6 | 1.5 | 71.8 | 10% |
| **Government Services** | 31.1 | 1.4 | 13.9 | 1.4 | 1.3 | 2.0 | | 51.1 | 7% |
| **Disbursements** | 2.6 | | 8.1 | 1.7 | -14.3 | 1.6 | | 0.3 | ~0% |
| **Total for Energy Source** | **334.7** | **101.2** | **93.4** | **80.5** | **64.7** | **43.9** | **6.4** | **724.8** | |
| **Share of All Incentives** | 46% | 14% | 13% | 11% | 9% | 6% | 1% | | 100% |

The dominance of oil and gas incentives is apparent in Exhibit 3.

[3] All estimates quoted are in constant 2006 dollars, unless otherwise noted, and refer to actual expenditures in the relevant fiscal year. Deflators used in calculating constant dollar values are provided in Appendix 4.
[4] Renewables are primarily wind and solar energy sources.

## Exhibit 3 – Comparison of Federal Expenditures for Energy Development, 1950–2006




Federal tax concessions for oil and gas are the largest of all incentives, amounting to about 80 percent of all tax-related allowances for energy. Regulation of prices on oil for stripper wells or new wells comprises the second largest amount of incentives aimed at a particular energy type.

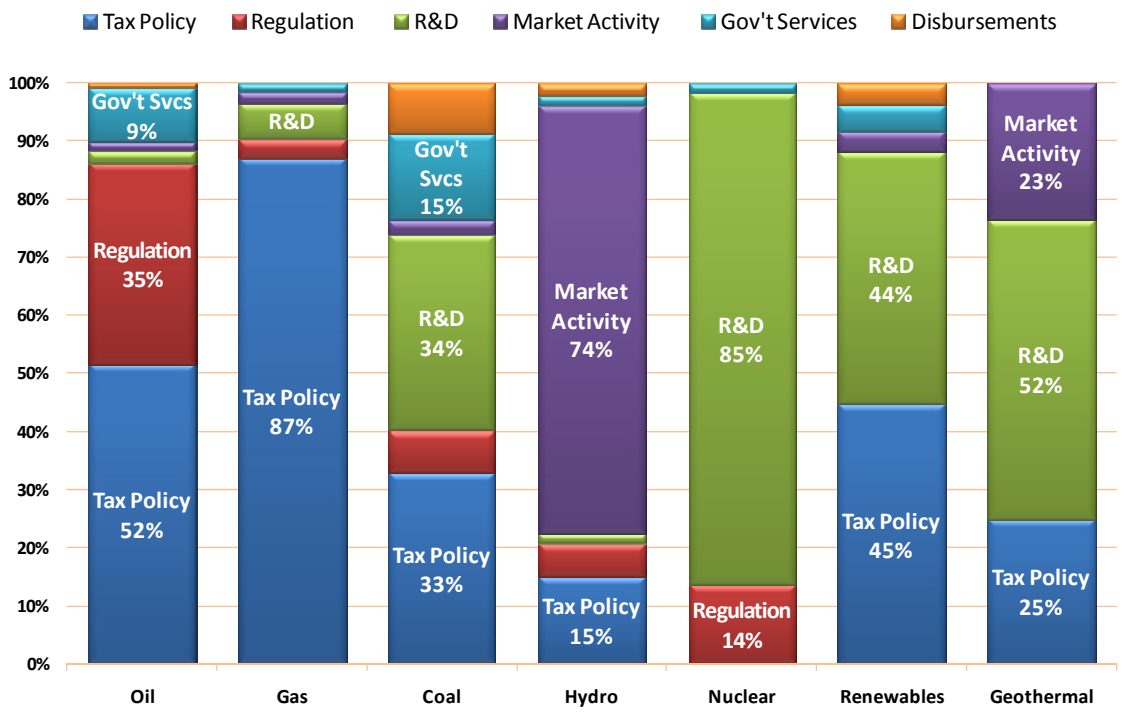
In the R&D category, nuclear energy received about half of the expenditures since 1950 and coal about a quarter of the total.

Some additional observations on the data:

- Oil and gas received approximately 60 percent ($436 billion) of federal spending to support energy since 1950. Oil alone received more than three-fourths ($335 billion) of this amount.
- Coal received approximately 13 percent ($93 billion) of federal spending.
- Nuclear received approximately 11 percent ($81 billion) of federal spending.
- Hydro received approximately 11 percent ($81 billion) of federal spending.
- Wind, solar and geothermal received approximately 7 percent ($50 billion).
- Nuclear energy was the target of about half ($67 billion) of the government's spending on energy R&D.
- About $39 billion (almost 60 percent) of the total spent on nuclear energy research since 1950 was spent before 1975 to explore a range of reactor concepts and potential applications for military and civilian uses.

Each energy type benefits from a mix of federal incentives. For the period 1950 to 2006, the mix for each energy type is illustrated in Exhibit 4.

**Exhibit 4 – Mix of Federal Expenditures for Each Energy Source**



## V. Research and Development Programs

Although research and development (R&D) is not the largest category of incentives provided by the federal government, it is the largest for nuclear energy. To put the nuclear R&D numbers into context, it is important to understand the overall trends in federally supported research.

The federal role in energy R&D became prominent in the 1950s, largely as a result of the Atomic Energy Acts of 1946 and 1954. During that time, the federal government invested significantly in energy-related R&D, particularly that relating to commercialization of nuclear technology as a source of electricity.

In the mid-1970s, federal support for all energy R&D grew sharply after the oil price shocks, with 1976 marking the beginning of rapid growth. This was the first budget year in which the then "reformed" federal energy organizations[5] were fully in place and the first year in which federal energy R&D funding priorities were broadly redirected from those extant before the oil crisis. For this reason, this report analyzes expenditures since 1950 to capture the heyday of nuclear research in the 1950s and early 1960s, but it focuses on the years 1976 to 2006, when oil prices were a critical factor in shaping energy policy. Additional information on the approach taken in analyzing and compiling federal R&D funding is provided in Appendix 5.

The nuclear energy R&D programs analyzed include those designed to promote civilian nuclear energy and to provide the technological base to support industry efforts to develop nuclear power as a source of baseload electricity. Generally, federal nuclear funding has been invested in services, products and technologies that are beyond the capability of private industry to fund alone. The nuclear R&D programs compiled for this analysis were funded by the U.S. Atomic Energy Commission, the U.S. Energy Research and Development Administration (ERDA) and DOE between 1950 and 2006. The compilation excludes defense atomic energy R&D programs (except for the portion that was directly applicable to the civilian nuclear program) as well as the fusion program. Fusion represents a distinct technology with little direct application to current commercial nuclear energy. The compilation excludes the waste management and environmental restoration expenditures associated with the civilian nuclear energy program, as these are included under generic incentives for nuclear energy, discussed previously in Section III. The nuclear energy R&D programs are discussed in more detail in Appendix 6.

The coal R&D program includes a variety of technologies for promoting the use of coal in an environmentally responsible manner. Programs compiled here include R&D on all aspects of coal technology funded at DOI's Bureau of Mines (BOM) from 1950 to 1996; environment-related coal R&D at the U.S. Environmental Protection Agency since the early 1970s; and the ERDA/DOE coal R&D program since 1976. Coal R&D programs are discussed in more detail in Appendix 7.

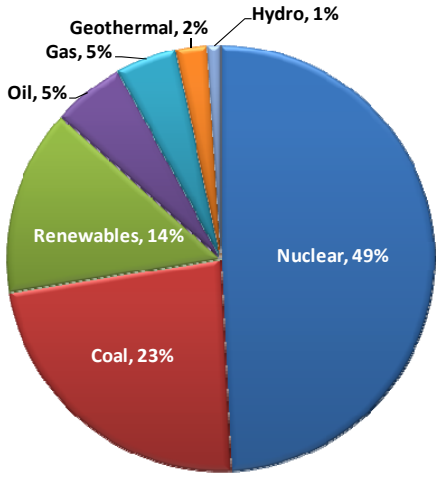
The renewable energy program is defined to include solar energy in all of its manifestations, e.g., photovoltaics, solar thermal systems, biomass and wind. It excludes all other renewable energy sources, specifically hydroelectric power and geothermal power, which are tabulated individually, and fusion energy. It includes all applicable renewable energy R&D undertaken between 1950 and

[5] The Federal Energy Administration, the Energy Research & Development Administration, and the NRC. Additional background on the federal agencies having a role in implementing federal energy policy is provided in Appendix 1.

2006 at ERDA, DOE, NASA, National Science Foundation (NSF), U.S. Department of Agriculture (USDA), AEC and other federal agencies. The renewable energy R&D programs are discussed in more detail in Appendix 8.

The distribution of federal R&D expenditures since 1950 is shown in Exhibit 5.

### Exhibit 5 – Allocation of Federal R&D Expenditures, 1950–2006




Analysis of federal budget data since 1950 shows:

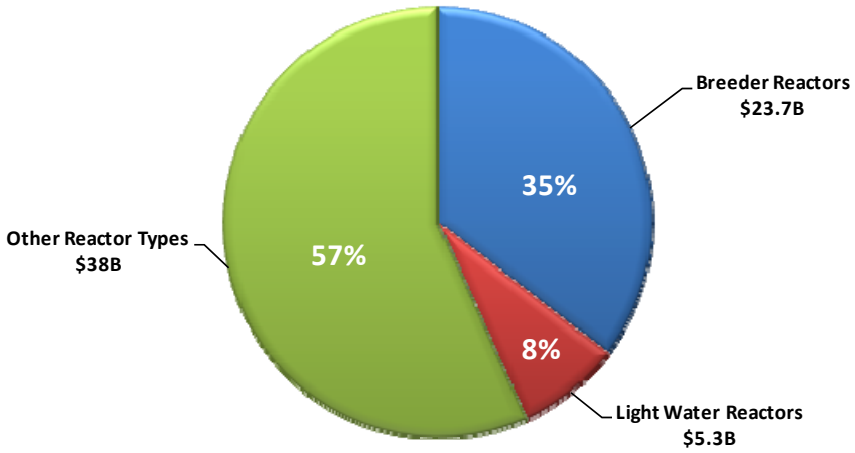
- Almost 90 percent of federal energy R&D spending was targeted at three energy types: nuclear, coal and renewables[6].
- Prior to 1976, the primary focus of federal R&D funding was nuclear energy, with an emphasis specifically on research on commercial applications of light water reactors and development of breeder reactors.
- The commercial nuclear energy R&D program peaked at $2.8 billion in 1978 and declined to a low of $75 million in 2001.
- Since 1976, only 6 percent of the total of $28 billion in nuclear energy R&D expenditures has been devoted to light water reactors.
- Of the total nuclear energy R&D expenditures from 1976 to 2006, 52 percent ($14.5 billion) was devoted to the breeder program. Since 1950, the breeder program consumed 35 percent—$23.7 billion of $67 billion—of civilian nuclear energy R&D. Funding for research on the breeder reactor ended in 1988.

[6] Of the energy sources commonly considered "renewables," hydro is tracked separately in this report and geothermal R&D funding was negligible compared to wind and solar R&D funding.

- The light water reactor program always has been a small portion of nuclear energy research, accounting for $5.3 billion (8 percent) of the $67 billion total R&D expenditures. Light water reactor technology produces about 20 percent of the nation's electricity.
- More than $38 billion was spent on R&D of other reactor types, including heavy water reactors, organic moderated reactors and gas cooled reactors, among others.

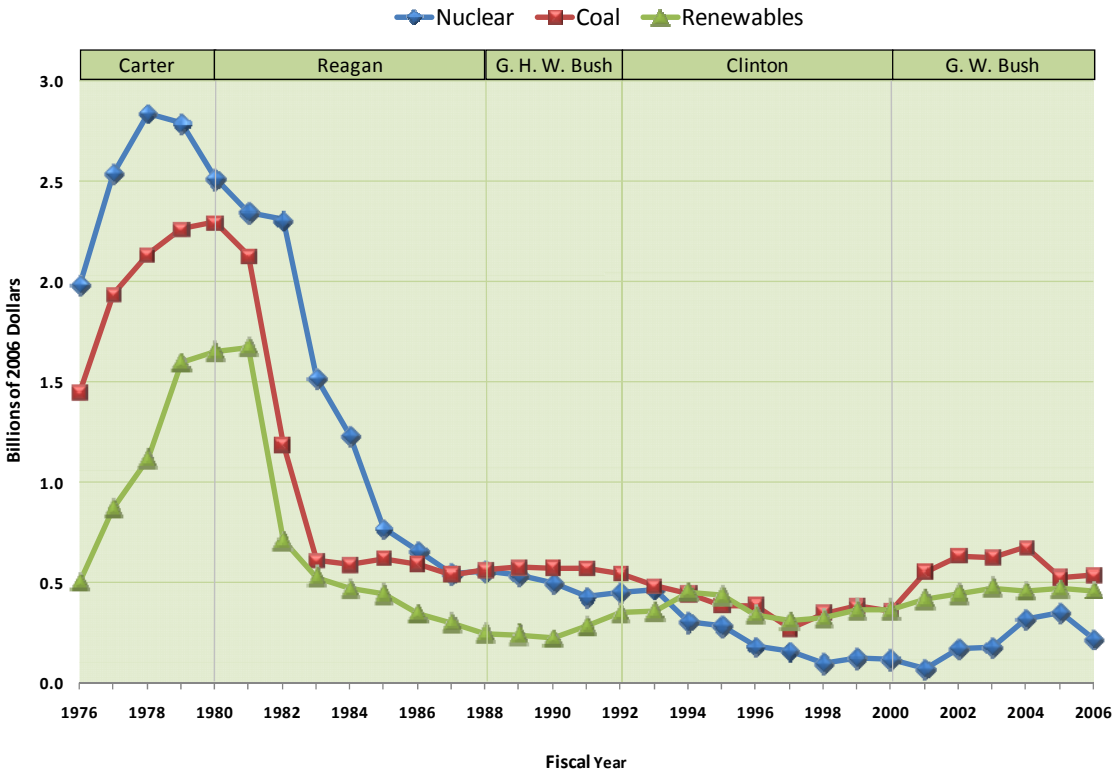
The distribution of funds for nuclear R&D is shown in Exhibit 6 below.

**Exhibit 6 – Allocation of Nuclear R&D Funding, 1950–2006**

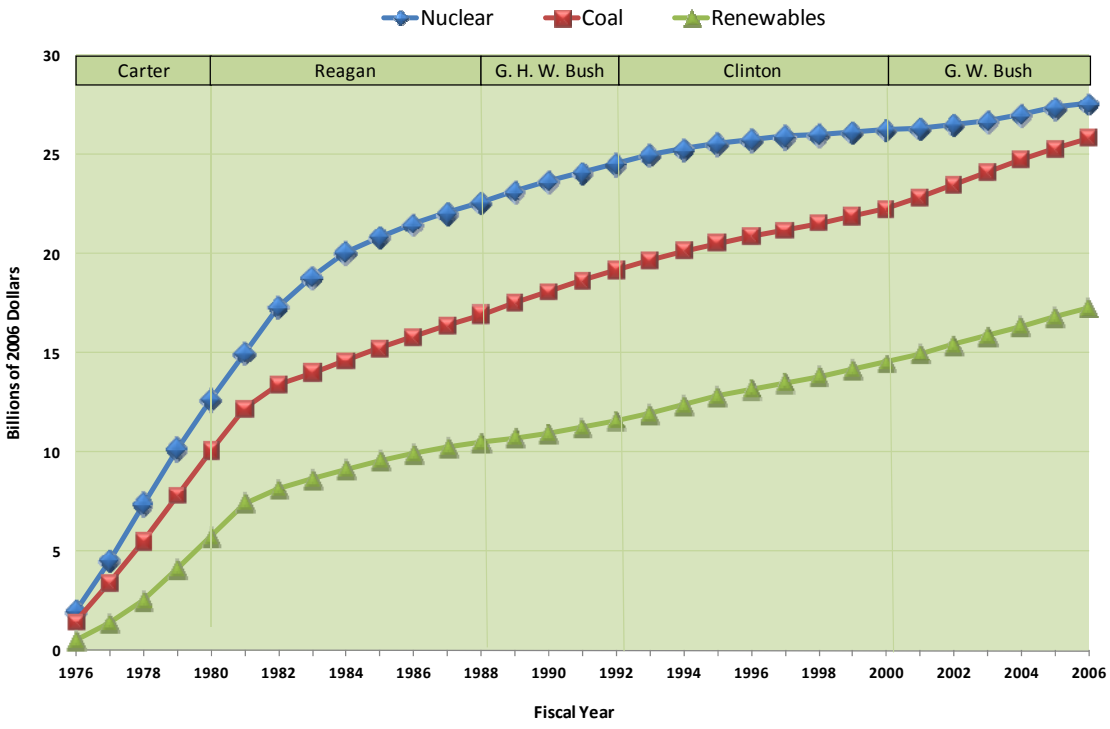



- Research and development expenditures for nuclear, coal and renewables expanded greatly after 1975, but this increase was especially marked for coal and renewables. Between 1976 and 2006 the federal government spent more than six times as much on coal R&D as it had in the previous quarter century and more than 10 times as much on wind and solar R&D.
- Annual R&D expenditures for all three technologies peaked between 1979 and 1981 and then declined dramatically. This decline continued through the late 1990s, as shown in Exhibit 7. Cumulative expenditures on R&D from 1976 to 2006 are shown in Exhibit 8. In the final 10 years of the study period (1997 to 2006), the cumulative expenditure for nuclear R&D was less than half that for coal and renewables (wind and solar), as shown in Exhibit 9.

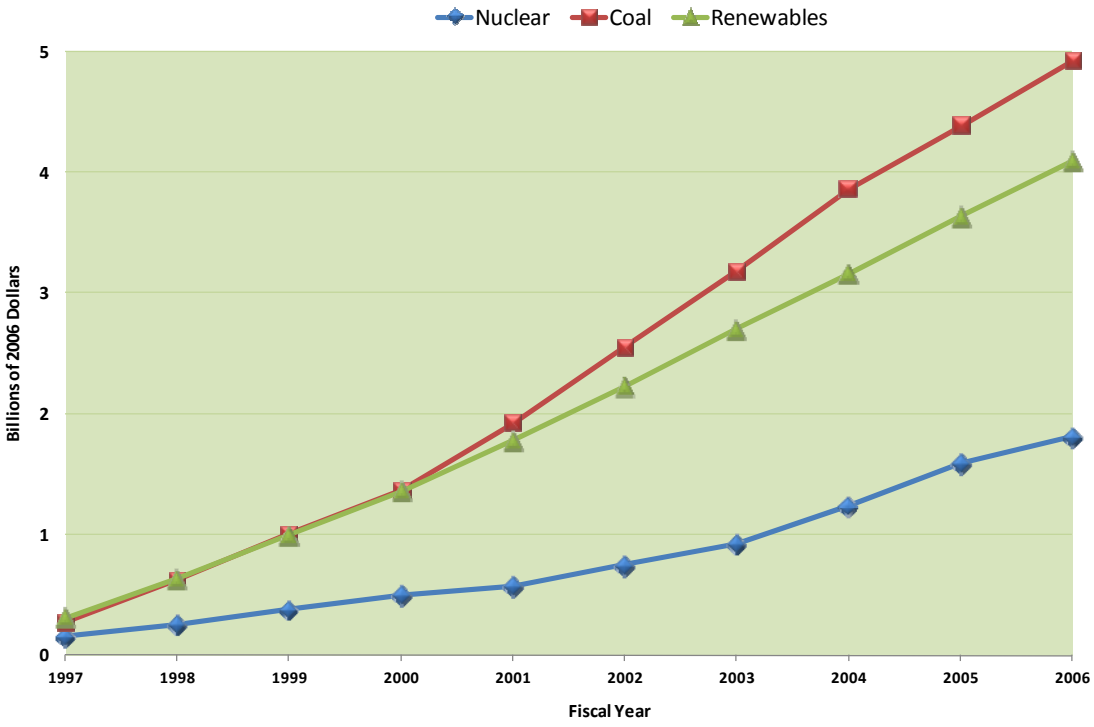
## Exhibit 7 – Annual Federal R&D Expenditures, 1976–2006




## Exhibit 8 – Cumulative Federal R&D Expenditures, 1976–2006



## Exhibit 9 – Cumulative Federal R&D Expenditures, 1997–2006



## VI. Conclusions

The common perception that federal energy incentives have favored nuclear energy at the expense of renewables, such as wind and solar, is not supported by the findings of this study. The largest beneficiaries of federal energy incentives have been oil and gas, receiving more than half of all incentives provided since 1950. The federal government's primary incentive to nuclear energy has been in the form of R&D programs, one of the more visible types of incentives identified. Since the end of funding for the breeder reactor program in 1988, federal spending on nuclear energy research has been less than spending on coal research and since 1994 has been less than spending on renewable energy research as well.

## Appendix 1 – Summary of Federal Energy Organizations

Until the early 1970s, energy policy was a low priority for the federal government, and responsibility for policy and funding was scattered throughout the government in the U.S. Atomic Energy Commission, the U.S. Department of the Interior, the U.S. Department of Treasury, the U.S. Department of State and other agencies. This changed dramatically during 1973, as the Arab oil embargo and the ensuing increases in oil prices focused the nation's attention as never before on the "energy crisis."

Reacting to this crisis atmosphere, President Nixon established the Federal Energy Office (FEO) by executive order in December 1973 to coordinate policy and to administer the increasingly complex energy regulations and allocation mandates. The Federal Energy Administration Act of 1974 transferred FEO's responsibilities to the newly created U.S. Federal Energy Administration (FEA).

In 1974, Congress also greatly expanded the federal government's role in energy R&D by creating the U.S. Energy Research and Development Administration (ERDA) as the focus of the nation's energy research efforts. The rationale for the creation of ERDA was threefold:

- There was a need for a single agency within which the government's greatly increased interest in and funding for energy R&D could be concentrated and centralized.
- It was felt that even a "reformed" AEC would be perceived as favoring nuclear energy over other options.
- There was concern that the AEC's dual functions of regulating the nuclear energy industry as well as funding research and promoting the development of nuclear energy were incompatible.

In 1975 the AEC was abolished and its regulatory functions were transferred to the U.S. Nuclear Regulatory Commission, its energy research functions were transferred to ERDA, and many—but not all—of the energy research programs scattered among different federal agencies were transferred to ERDA. FEA continued to administer most energy regulations—primarily petroleum and natural gas price controls and allocations.

During 1976 and 1977, Presidents Ford and Carter both recommended the creation of a centralized, Cabinet-level energy department, and in 1978 the energy bureaucracy was again reorganized. ERDA and FEA became part of the newly formed U.S. Department of Energy, while the Nuclear Regulatory Commission remained an independent agency. The U.S. Federal Power Commission, which had been an independent agency since its inception, became the semiautonomous U.S. Federal Energy Regulatory Commission (FERC) within DOE.

In the early 1980s, the Reagan Administration proposed abolishing DOE and in the fiscal 1983 budget proposed transferring the energy R&D budget to an "Energy Research and Technology Administration" to be created within the Commerce Department. However, this proposal was not implemented, and the federal energy bureaucracy has remained relatively intact since 1978.

A list of acronyms for these and other federal agencies mentioned in this report is provided below.

## List of Acronyms

| | |
|---|---|
| AEC | U.S. Atomic Energy Commission |
| BEA | Bureau of Economic Analysis, U.S. Department of Commerce |
| BLM | Bureau of Land Management, U.S. Department of the Interior |
| BOM | Bureau of Mines, U.S. Department of the Interior |
| CBO | Congressional Budget Office |
| DOE | U.S. Department of Energy |
| DOC | U.S. Department of Commerce |
| DOI | U.S. Department of the Interior |
| EPA | U.S. Environmental Protection Agency |
| ERDA | U.S. Energy Research and Development Administration |
| FEA | U.S. Federal Energy Administration |
| FEO | U.S. Federal Energy Office |
| FERC | U.S. Federal Energy Regulatory Commission |
| NASA | National Aeronautics and Space Administration |
| NSF | National Science Foundation |
| OMB | Office of Management and Budget |
| OTA | Office of Technology Assessment |
| USDA | U.S. Department of Agriculture |
| USGS | U.S. Geological Survey, U.S. Department of the Interior |

## Appendix 2 – Sources and Methods

Part A of this appendix discusses the source documents used in this study. Part B shows how federal programs identified in this study align with the incentive types and energy sources tabulated herein.

### A. Source Documents

The major sources for the data in this report include the federal budget documents compiled by the U.S. Departments of Energy, Interior, and Agriculture, the U.S. Environmental Protection Agency, the Office of Management and Budget, the Congressional Budget Office, the U.S. Nuclear Regulatory Commission, the Energy Research and Development Administration, the U.S. Atomic Energy Commission, the Office of Technology Assessment (OTA), the National Aeronautics and Space Administration, and other federal agencies. Significant source documents are listed in Exhibit 10.

**Exhibit 10 – Source Documents**

| PERIOD | SOURCES |
|---|---|
| **1950–2006** | OMB's annual "Budget of the United States Government," its appendices and its special studies. |
| **1950–1978** | DOE-funded study, "An Analysis of the Results of Federal Incentives Used to Stimulate Energy Production," Richland, Washington: Bruce W. Cone, et. al., Battelle Pacific Northwest Laboratory, 1980. |
| **1975–2006**[7] | The annual budgets and supporting documents of DOI, USDA, NASA and EPA. |
| **1978–2006** | DOE's annual budgets, their appendices and special reports, and detailed congressional budget submissions, requests, justifications, revisions, and program defenses. |
| **1983** | Budget of the Department of Commerce (the Reagan administration had proposed abolishing DOE and its research functions were to be transferred to a newly created Energy Research and Technology Administration within Commerce). |
| **1975–1978** | ERDA's annual budgets, their appendices and special reports, and ERDA's detailed congressional budget submissions, requests, justifications, revisions and program defenses. |
| **1950–1974** | AEC's annual reports and their appendices, AEC special studies, annual AEC financial statements, and congressional hearings documents from the Joint Committee on Atomic Energy. |

[7] Includes the 1976 "Transition Quarter," running from July 1, 1976 through September 30, 1976, as the Congress shifted the start of the federal fiscal year to October 1, where it remains.

The inflation and gross domestic product estimates for 2006 were those contained in the "Budget of the United States Government, Fiscal Year 2007." The R&D expenditure estimates used were the actual dollars as expended in the year in question.

In addition, invaluable assistance was rendered to the authors by numerous individuals in the respective federal agency programs, budget and comptroller offices, federal librarians, the DOE historian, and by current and former staff from the relevant federal agencies and the U.S. Congress.

## B. Alignment of Federal Programs to Incentive Categories

The incentives discussed in this report are the major ones that have been used by the federal government to stimulate energy development and account for 90 to 95 percent of the incentive costs estimated through 2006. Exhibit 11 summarizes the alignment of key federal programs to the incentive types and energy sources identified in this study.

**Exhibit 11 – Alignment of Federal Programs to Incentive Types**

| Targeted Energy | Federal Program or Activity | Incentive Type | Year Started |
|---|---|---|---|
| **Nuclear** | Research and Development Activities | R&D | 1950 |
| | Regulation of Commercial Nuclear Energy | Regulation | 1960 |
| | Waste Management and Disposal | Disbursements | 1982 |
| | Enrichment Plants | Market Activity | 1943 |
| | Liability Insurance | Disbursements | 1957 |
| | Uranium Mining Industry | Market Activity | 1971 |
| | Nuclear Waste Fund | Disbursements | 1982 |
| | All Other Federal Support Activities | Government Services | 1950 |
| **Coal** | Research and Development Activities | R&D | 1950 |
| | U.S. Geological Survey | R&D | 1950 |
| | Bureau of Land Management | Market Activity | 1950 |
| | Percentage Depletion Allowance | Tax Policy | 1950 |
| | Mine Health and Safety | Regulation | 1950 |
| | Bureau of Mines | R&D | 1964 |
| | Black Lung Disability Trust Fund | Disbursements | 1977 |
| | Abandoned Mine Reclamation Fund | Disbursements | 1977 |
| | Transportation, Ports and Waterways | Government Services | 1950 |
| **Oil** | Research and Development Activities | R&D | 1951 |
| | U.S. Geological Survey | R&D | 1950 |
| | Bureau of Land Management | Market Activity | 1950 |
| | Bureau of Mines | R&D | 1964 |
| | Percentage Depletion Allowance | Tax Policy | 1950 |
| | Maintenance of Ports and Waterways | Regulation | 1950 |
| | Stripper Well Price Incentives | Regulation | 1944–45; 1974–81 |
| | Regulation | Regulation | 1974 |
| | Intangible Drilling Expenses | Tax Policy | 1950 |
| | High Rate of Return for Oil Pipelines | Regulation | 1921–51 |
| | Leaking Underground Storage Tank Trust Fund | Disbursements | 1986 |

| Exhibit 11 – Alignment of Federal Programs to Incentive Types | | | |
|---|---|---|---|
| **Targeted Energy** | **Federal Program or Activity** | **Incentive Type** | **Year Started** |
| | Oil Spill Liability Fund | Disbursements | 1986 |
| | Subsidies for Oil Tankers | Disbursements | 1970 |
| | | | |
| | | | |
| | Royalty Relief | Tax Policy | 1995 |
| **Natural Gas** | Research and Development Activities | R&D | 1951 |
| | Regulation | Regulation | 1938 |
| | Wellhead Price Controls | Regulation | 1955 |
| | U. S. Geological Survey | R&D | 1950 |
| | Bureau of Land Management | Market Activity | 1950 |
| | Pipeline Safety Fund | Disbursements | 1979 |
| | Section 29 Tax Credits | Tax Policy | 1980 |
| | Intangible Drilling Expenses | Tax Policy | 1950 |
| | Royalty Relief | Tax Policy | 1995 |
| **Hydroelectric Energy** | Research and Development Activities | R&D | 1950 |
| | Construction and Operation of Federal Dams | Market Activity | 1933 |
| | Exemption of Pwr Revenues From Fed Taxation | Tax Policy | 1938 |
| | Low Interest Loans | Market Activity | 1933 |
| | Federal Regulation | Regulation | 1971 |
| | Construction/Operation of Fed Transmission Sys | Market Activity | 1936 |
| **Renewables (Solar and Wind)** | Research and Development Activities | R&D | 1950 |
| | Tax Credits and Deductions | Tax Policy | 1978 |
| | Federal Programs and Disbursements | Disbursements | 1976 |
| | Market Activities and Demonstration Programs | Market Activity | 1976 |
| | Renewable Energy Production Incentive | Disbursements | 1993 |
| | Commodity Credit Corporation Programs | Government Services | 2001 |
| | All Other Federal Support Activities | Government Services | 1973 |
| **Geothermal** | Research and Development Activities | R&D | 1950 |
| | Tax Credits and Deductions | Tax Policy | 1978 |
| | Market Activities and Demonstration Programs | Market Activity | 1976 |

## Appendix 3 – Application of Incentive Types to Energy Sources

The following notes give additional explanation for the estimates of incentive costs provided in this report (e.g., Exhibit 1).

1. **Nuclear Energy.** Through 2006, federal incentives for nuclear netted to almost $65 billion—9 percent of the federal incentives for energy development.

   a. Tax Policy. Prior to the Energy Policy Act of 2005 (EPAct 2005), there were no tax incentives specifically designed to subsidize nuclear energy[8]. In EPAct 2005, Congress provided $6 billion in production tax credits for new nuclear plants.

   b. Regulation. Approximately $10.9 billion through 2006; includes the cost of administering the NRC/AEC and is net of the regulatory user fees paid by utilities.

   c. R&D. Primarily AEC, ERDA and DOE expenditures, totaling $66.8 billion through 2006.

   d. Market Activity. There has been no direct federal government involvement in market activity with respect to commercial nuclear energy.

   e. Government Services. Federal support activities related to nuclear energy development exist in about 45 departments and agencies other than DOE and the NRC, but the expenditures are very small compared to the funds spent by DOE and the NRC. The authors estimated that through 2006 the total for all other federal incentives and support activities was about $1.3 billion.

   f. Disbursements. There initially were federal disbursements for nuclear energy for waste management and disposal; these funds are included under R&D monies. However, under the Nuclear Waste Policy Act of 1982, nuclear utilities are assessed the costs of developing a high-level waste repository for spent fuel from nuclear plants. Through 2006 this fund had accumulated $20 billion more than had been disbursed. Through 2006 the federal government has expended approximately $5.7 billion for environmental restoration related to commercial nuclear energy. Thus, federal disbursements for nuclear energy net to -$14.3 billion

[8] See the discussion in Roger H. Bezdek and Robert M. Wendling's "Costs and Results of Federal Incentives for Commercial Nuclear Energy," Energy Systems and Policy, Vol. 15, 1991, pp. 269-293, and U.S. Energy Information Administration, Federal Financial Interventions and Subsidies in Energy Markets, September 1999. The Tax Reform Act of 1986 included a 15-year accelerated depreciation period for nuclear power plants. However, under the reference tax law standard used by the U.S. Department of the Treasury, OMB, and the Joint Committee on Taxation of the U.S. Congress to estimate tax expenditures, the system of depreciation allowances provided by this act is the reference tax law baseline for investments. Thus, there are no specific tax expenditures for nuclear from accelerated depreciation.

2. **Coal.** Through 2006, federal incentives for coal totaled $93.4 billion—13 percent of the federal incentives for energy development.

   a. Tax Policy. Through 2006 the authors estimated that the percentage depletion allowance for coal, the expensing of exploration and development costs, capital gains treatment of royalties on coal, and exclusion of interest on energy facility bonds resulted in a tax subsidy of $30.7 billion.

   b. Regulation. Federal expenditures for regulating mine health and safety and other aspects of the coal industry totaled $6.9 billion through 2006.

   c. R&D. Through 2006, the coal industry received $31.5 billion in R&D funding. Most of these expenditures were federal coal R&D monies. However, significant expenditures were also derived from prorated expenditures of selected U.S. Geological Survey and BOM programs.

   d. Market Activity. Market activity incentives for the coal industry totaled $2.3 billion through 2006, through the activities of BLM and other federal agencies.

   e. Government Services. Federal support of ports and waterways (primarily through the U.S. Army Corps of Engineers), allocated and prorated to the coal industry totaled $13.9 billion through 2006.

   f. Disbursements. As of 2006, the Black Lung Disability Trust Fund had a negative balance of $9.9 billion, and the Abandoned Mine Reclamation Fund had a positive balance of $1.8 billion, resulting in net federal disbursements for the coal industry of approximately $8.1 billion.

3. **Oil.** Through 2006, federal incentives for oil totaled $335 billion—46 percent of the federal incentives for energy development.

   a. Tax Policy. The authors estimate that, through 2006, tax incentives for the oil industry totaled $172.9 billion. These tax expenditures resulted primarily from the percentage depletion allowance and from deducting as a current expense “intangible drilling and development costs.”

   b. Regulation. Incentive costs under this category totaled $115.6 billion through 2006. These resulted from: 1) the exemption from price controls (during their existence) of oil produced from “stripper wells;” 2) the two-tier price control system, which was enacted as an incentive for the production of “new” oil; 3) the costs of oil industry regulation; and 4) the higher-than-average rate of return allowed on oil pipelines.

   c. R&D. Through 2006, federal R&D incentives for the oil industry totaled $7.4 billion. These resulted from: 1) federal R&D expenditures for the oil industry, and 2) the prorated costs of selected USGS and BOM programs.

d. Market Activity. Market activity incentives for the oil industry refer to the planning, leasing, resource management and related activities of the BLM. The authors estimated that the prorated costs of these totaled $5.1 billion through 2006.

e. Government Services. Government services incentives ($31.1 billion) resulted primarily from the prorated cost of maintaining ports and inland waterways and, to a lesser extent, from the support of numerous federal agencies through 2006.

f. Disbursements. Through 2006, the federal government disbursed approximately $5.8 billion to the oil industry, primarily through subsidies for construction and operating costs of oil tankers. However, as of 2006, the combined balances in the Leaking Underground Storage Tank Trust Fund and the Oil Spill Liability Fund totaled $3.2 billion. Thus, the net federal disbursements for the oil industry totaled $2.6 billion through 2006.

4. **Natural Gas.** Through 2006, federal incentives for natural gas totaled $101 billion—14 percent of the federal incentives for energy development.

a. Tax Policy. The authors estimate that through 2006, tax incentives for the natural gas industry totaled $88.3 billion. These tax expenditures resulted primarily from: 1) the percentage depletion allowance and from deducting as a current expense "intangible drilling and development costs"—both allocated on the basis of wellhead values and 2) the alternative fuel production credit.

b. Regulation. Incentive costs under this category totaled $3.3 billion through 2006. These resulted from the net effects of the costs of federal regulation and the net effects of wellhead price controls, which historically have served at some times as an incentive and at other times as a disincentive for natural gas production.

c. R&D. Through 2006, federal R&D funds for the natural gas industry totaled $6.2 billion. These resulted from federal R&D expenditures for the gas industry and the prorated costs of selected USGS and BOM programs.

d. Market Activity. Market activity incentives for the natural gas industry refer to the planning, leasing, resource management and related activities of the BLM. The authors estimated that the prorated costs of these totaled $2.0 billion through 2006.

e. Government Services. Traditional services incentives ($1.4 billion) resulted primarily from miscellaneous services provided by the federal government to the industry through 2006.

f. Disbursements. Federal government disbursements to the natural gas industry were negligible.

5. **Hydroelectric.** Through 2006, federal incentives for hydroelectric energy totaled $80.5 billion—11 percent of the federal incentives for energy development.

a. Tax Policy. The authors estimate that, through 2006, the exemption of power revenues from federal taxes resulted in a tax expenditure subsidy for the development of hydroelectric energy of $12.1 billion.

b. Regulation. Expenditures for the regulation of hydroelectric energy through FERC and other regulatory agencies totaled approximately $4.7 billion through 2006.

c. R&D. Through 2006, federal R&D expenditures for hydroelectric energy in DOE, its predecessors and the U.S. Army Corps of Engineers totaled approximately $1.3 billion.

d. Government Services. Traditional services through the support of numerous federal agencies resulted in a subsidy for hydroelectric energy of $1.4 billion through 2006.

e. Market Activity. Market activity incentives for hydroelectric energy include federal construction and operation of dams and transmission facilities—estimated as the portion of the net investment in construction and operation of dams allocated to power development and the relevant transmission facilities—and the net expenditures of the power marketing administrations. These incentives totaled $59.3 billion through 2006.

f. Disbursements. Through 2006 the federal government disbursed $1.7 billion for hydroelectric energy development.

6. **Renewables.** Through 2006, federal incentives for renewables (solar, wind and biofuels) totaled $43.9 billion—6 percent of federal incentives for energy development.

a. Tax Policy. The authors estimate that, through 2006, tax incentives for renewable energy totaled $19.6 billion. These tax expenditures resulted primarily from targeted, exclusive federal tax credits and deductions for renewable energy applications for individuals and businesses beginning in 1978—including the alcohol fuel credit and the partial exemption from the excise tax for alcohol fuels.

b. Regulation. Federal regulation costs for renewable energy were negligible.

c. R&D. Through 2006, federal R&D incentives for renewable energy totaled $19.1 billion. These resulted primarily from federal R&D expenditures by ERDA and DOE.

d. Government Services. Government services incentives of $2 billion resulted primarily from miscellaneous services provided by various federal agencies, including the Commodity Credit Corporation, to encourage renewable energy development.

e. Market Activity. Market activity incentives for renewable energy include commercialization programs, demonstration projects and outreach programs and totaled $1.6 billion through 2006.

f. Disbursements. Federal disbursements to encourage renewable energy utilization through various federal programs, including the Renewable Energy Production Incentive, totaled $1.6 billion through 2006.

7. **Geothermal Energy**. Through 2006, federal incentives for geothermal energy totaled $6.4 billion—1 percent of the federal incentives for energy development.

a. Tax Policy. The authors estimate that, through 2006, targeted tax expenditure incentives for geothermal energy totaled $1.6 billion.

b. Regulation. Federal regulation costs for geothermal energy were negligible.

c. R&D. Through 2006, federal R&D spending for geothermal energy totaled $3.3 billion. These resulted primarily from federal R&D expenditures by ERDA and DOE.

d. Government Services. Government services incentives for geothermal energy were negligible.

e. Market Activity. Market activity incentives for geothermal energy include commercialization programs and demonstration projects and totaled approximately $1.5 billion through 2006.

f. Disbursements. Federal disbursements to encourage geothermal energy were negligible.

## Appendix 4 – Current and Constant Dollar Estimates

This analysis spans a period of 56 years (1950–2006), during which the general price level in the United States increased more than sixfold. Further, price increases were not distributed uniformly over the period, with the most severe inflation occurring in the early 1950s, the 1970s and early 1980s. Thus, the only meaningful way to compare and analyze federal energy R&D expenditures over this period is to use values expressed in constant dollars. Obviously, it would be misleading to equate an R&D dollar expended in 1973 with one spent in 2006, since the price level in the latter year is more than three times that of the former year. Aside from the general distortions, use of current dollar data in the analysis would, for example, seriously undercount nuclear energy R&D expenditures incurred during the 1950s and 1960s, which were substantial, and overestimate R&D funding for solar and renewable energy programs, which only began to be substantial during the mid-1970s. Therefore, throughout this report all the estimates given are stated in constant 2006 dollars.

The authors derived the constant 2006 dollar data (2006 = 1.00) using GDP deflators to convert current dollar data into 2006 base year estimates. It is preferable in an analysis such as this to use the GDP deflators instead of the more widely known U.S. Consumer Price Index deflators.

The U.S. Consumer Price Index is a measure of the average change in prices over time in a fixed "market basket" of goods and services purchased either by urban wage earners and clerical workers or by all urban consumers and is compiled by the Bureau of Labor Statistics of the U.S. Department of Labor. The index is based on prices of food, clothing, shelter, fuels, transportation fares, charges for doctors' and dentists' services, drugs, etc. purchased for day-to-day living. In calculating the index, each item is assigned a weight to account for its relative importance in consumers' budgets. Price changes for the various items in each location are then averaged.

The index is the most widely publicized measure of inflation, and it is broad-ranging and readily comprehensible. However, the implicit GDP deflator is the most comprehensive price index available—not the U.S. Consumer Price Index.

The implicit price deflator (IPD), compiled by the Bureau of Economic Analysis of the U.S. Department of Commerce, is a by-product of the deflation of GDP and is derived as the ratio of current- to constant-dollar GDP (multiplied by 100). It is the weighted average of the detailed price indices used in the deflation of GDP, but they are combined using weights that reflect the composition of GDP in each period. Thus, changes in the implicit price deflator reflect not only changes in prices but also changes in the composition of GDP. It is issued quarterly by BEA.

The IPD is not independently derived by a direct price collection program. Rather, as noted, it represents the ratio between current-dollar GDP and constant-dollar GDP multiplied by 100. The result is an aggregate price index that is affected by changing expenditure patterns each year. Because of its indirect derivation, the quality of the IPD is closely correlated to that of the various price series used in converting national output to constant dollars. In contrast, the U.S. Consumer Price Index is a fixed weight index in which the contents of the "market basket" are kept constant over a long period (five to 10 years). It is specifically designed to measure directly changes in prices of identical or comparable items over time.

Conceptually, the IPD measures the general price level of all final goods and services (including government) produced during a specific period. Thus, the IPD is the only official index that attempts to measure overall price behavior of all goods and services in the nation. The U.S. Consumer Price Index is restricted to a narrower universe. The movement of the IPD usually closely parallels the movement of the U.S. Consumer Price Index but is rarely identical to it. The implicit GDP deflators are the ones used in this study, and the deflators for 1950–2006 are listed in Exhibit 12.

### Exhibit 12 – U.S. Gross Domestic Product Deflators Used

**(2006 = 100)**

| YEAR | GDP DEFLATOR | YEAR | GDP DEFLATOR | YEAR | GDP DEFLATOR |
|---|---|---|---|---|---|
| **1950** | 14.25 | **1970** | 23.73 | **1990** | 70.31 |
| **1951** | 15.27 | **1971** | 24.91 | **1991** | 72.77 |
| **1952** | 15.53 | **1972** | 26.00 | **1992** | 74.44 |
| **1953** | 15.72 | **1973** | 27.45 | **1993** | 76.16 |
| **1954** | 15.87 | **1974** | 29.92 | **1994** | 77.78 |
| **1955** | 16.15 | **1975** | 32.75 | **1995** | 79.37 |
| **1956** | 16.71 | **1976** | 34.64 | **1996** | 80.88 |
| **1957** | 17.27 | **1977** | 36.84 | **1997** | 82.22 |
| **1958** | 17.66 | **1978** | 39.43 | **1998** | 83.13 |
| **1959** | 17.88 | **1979** | 42.70 | **1999** | 84.34 |
| **1960** | 18.13 | **1980** | 46.57 | **2000** | 86.18 |
| **1961** | 18.34 | **1981** | 50.95 | **2001** | 88.24 |
| **1962** | 18.59 | **1982** | 54.05 | **2002** | 89.78 |
| **1963** | 18.78 | **1983** | 56.19 | **2003** | 91.70 |
| **1964** | 19.07 | **1984** | 58.30 | **2004** | 94.30 |
| **1965** | 19.42 | **1985** | 60.08 | **2005** | 97.15 |
| **1966** | 19.97 | **1986** | 61.40 | **2006** | 100.00 |
| **1967** | 20.59 | **1987** | 63.08 | | |
| **1968** | 21.47 | **1988** | 65.23 | | |
| **1969** | 22.53 | **1989** | 67.70 | | |

## Appendix 5 – Reconciliation of R&D Program Categories and Budget Data

Substantial resources were devoted in this study to program and budget reconciliations for the three technologies on which this analysis of R&D focused—nuclear, coal and renewables. Required here were detailed R&D expenditures by technology, program and subprogram components over a period of 56 years. The major challenges in deriving these data included the following:

- The R&D expenditures involved spanned nearly six decades, during which some of the programs, subprograms and/or technologies did not exist.
- The interest (and detailed information available) varied in cycles over the period, from acute intensity to a total lack thereof.
- A coherent, readily identifiable R&D program for one of the technologies (renewables) did not even exist until the mid 1970s.
- The budget estimates for nuclear energy R&D during most of the 1950s were classified and intentionally aggregated so as to be indiscernible.
- Program and budget classifications for all three technologies changed—something sometimes significantly—on almost a year-by-year basis.
- Individual R&D programs and subprograms were continually redefined, reclassified, disaggregated and reaggregated.
- Similar programs had different titles, definitions and subprogram components across different federal agencies.
- Some R&D programs appeared, disappeared and then later reappeared under different definitions and headings.
- Budget expenditures estimates for the R&D programs were available according to different accounting conventions: appropriations, adjusted appropriations, authorizations, obligations, outlays, expenditures, etc.
- During 1976, the federal fiscal year was redefined.
- Usually the budget expenditures for a specific detailed program for a given year differed depending on the source, program definition, year the estimate was made, inclusion or exclusion of carry-forward monies and/or rescissions, amount of reprogramming incorporated, the accounting of "overhead" (management, program direction, policy and analysis, planning, etc.), the distinction made between operating and capital expenses, the way that funds allocated to the DOE labs were classified, and other factors.

Given these challenges, this analysis was driven by three major principles:

1. The authors wished to distinguish between the period 1950-1975 and 1976-2006, with most of the analysis and budget detail devoted to the latter period.

As noted in the report, 1976 was a watershed year for federal energy R&D, as it represents the first year when the nation's reordered energy R&D budget priorities were firmly in place. Further,

prior to 1976 the budget detail for some energy R&D programs—coal and especially those in the renewables area—was lacking.

2. Second, in deriving R&D program categories for the period 1976-2006 the authors desired classifications that were comprehensive and contained meaningful program detail.

To list for each of the 30 years every program or subprogram that existed in any year would have made a meaningful time series analysis of the budget priorities impossible. On the other hand, in aggregating and classifying the budget categories, meaningful programmatic detail—that was both consistent and accurate—had to be preserved.

3. Third, the R&D expenditure estimates used were actual dollars as expended in the year in question.

As noted, the budget expenditures for a specific detailed program for a given year differed depending on the source, program definition, year the estimate was made, inclusion or exclusion of carry-forward monies and/or rescissions, amount of reprogramming incorporated, the accounting for "overhead" (management, program direction, policy and analysis, planning, etc.), the distinction made between operating and capital expenses, the manner in which funds allocated to the DOE labs were included, and other factors. Thus, the answer to the question "How much money was spent on energy R&D program X in year Y?" can be answered in several different ways, depending both on how the program is defined and the way that the expenditure estimate is derived.

The definition of an energy R&D program can differ even for seemingly identical programs. For example:

- Is the program inclusive or exclusive of overhead?
- Does the program include both operating and capital expenditures?
- Is the program inclusive of all the appropriate subprogram elements?
- Does the program include the appropriate functions at the DOE labs?
- Is the program inclusive of other agencies' expenditures on the same function?

In their reconciliations the authors strove to aggregate the program definitions as much as possible in a consistent manner. Thus, for example, an expenditure estimate for the breeder program includes all monies spent on that program irrespective of the source of funds or the organization that spent them.

Concerning expenditures in the year in question, program expenditures estimates will often differ significantly and a definitive estimate is not usually available until two or three years hence in the appropriate budget documents. Thus, the definitive estimate of the funds actually expended on a specific, detailed energy R&D program (incorporating all rescissions, pass-throughs, carry-forwards, etc.) in 2006 would not be available until the DOE and the OMB budget documents for 2007 or 2008 are available. The authors' budget estimates of actual monies "as spent in the year in question" were thus based, where possible, on the DOE and OMB budget documents subsequently published two or three years hence—after the final revisions had been made.

# Appendix 6 – Nuclear R&D Expenditures

## A. Background

Policymakers recognized early that, although nuclear energy had great potential, its development involved larger financial resources and risks than were feasible for private industry alone. Through federal leadership, an arrangement was established with industry to provide a framework to address the risks and to develop the resource. Development early of the commercial nuclear energy program derived from personnel, facilities, technology and contracting policies that had their genesis in World War II. The technology grew out of military applications of atomic power—the weapons and naval reactor programs—and control was exercised by the federal government under conditions of secrecy.

The Atomic Energy Act of 1946 (AEA) created the basis for development of nuclear energy, transferring the atomic energy program to civilian control. The act established two entities to develop nuclear energy: the AEC in the executive branch (with the charter to develop fission energy) and the Joint Committee on Atomic Energy in Congress. AEC contracting arrangements created a third party, the industrial suppliers, and through 1974 this three-member group remained a stable coalition working together to commercialize the technology.

The 1954 AEA amendments paved the way for industrial participation in nuclear energy development by declassifying information, establishing procedures by which private interests could obtain required classified data, and permitting private industry to own and operate nuclear reactors. Subsequently, the 1964 AEA amendments permitted private ownership of fissionable material, and full private ownership was reached in steps over a period of years. The AEC encouraged the growth of the industry, and because of the financial risks involved, a framework of government-industry cooperation was developed for financing early nuclear energy plants. The Civilian Reactor Development Program (CRDP) provided R&D support, access to technology, waiver of fuel use charges, fuel fabrication and the training of personnel. The AEC's goal of transferring the federally developed reactor and fuel cycle technologies to the private sector was achieved, and all steps in the fuel cycle are currently either funded or handled directly by industry.[9]

As noted in Appendix 1, by the mid-1970s there was concern that the AEC's dual functions of regulating the industry as well as funding research and promoting the development of nuclear energy were incompatible. In 1975, the AEC was abolished and its regulatory functions were transferred to the NRC, while its research functions were transferred to ERDA. In 1977, ERDA became part of DOE.

Federal policy has succeeded in creating a viable commercial nuclear energy industry that has developed into a significant portion of the nation's energy resource base. In 2006, nuclear energy produced about 20 percent of U.S. electricity and supplied approximately 8 percent of total U.S. energy consumption.

[9] The federal government's nuclear energy commercialization program was successful and, at present, all costs and externalities are borne by private industry.

## B. The Commercial Nuclear Energy Research Program

DOE's nuclear energy programs are designed to promote civilian nuclear energy and to provide the technological base to support industry efforts to continue the development of nuclear power as an economic and environmentally acceptable means of generating baseload electric power. The R&D program has included research on light water reactors, breeder reactor systems, fuel reprocessing technologies, space power systems, advanced radioisotope power systems, nuclear energy plant optimization and other technologies. The major program components supported since 1976 include:

- Nuclear Energy Research Initiative
- isotope support
- Advanced Fuel Cycle Initiative
- commercial nuclear waste
- spent nuclear fuel
- light water reactors
- converter reactors (other than light water)
- advanced nuclear systems
- facilities
- advanced radioisotope power systems
- space reactor power systems
- nuclear fuel cycle
- the breeder program
- remedial action
- university reactor fuel assistance and support
- Nuclear Hydrogen Initiative
- Advanced Nuclear Medicine Initiative
- advanced test reactor fusion irradiation
- program direction
- policy and management and miscellaneous
- civilian waste R&D.

## C. Research and Development Expenditures

Nuclear energy development has relied from inception on a broad R&D program conducted by national laboratories, industrial concerns, and private and public institutions under federal contract, as well as by industrial firms with their own funding. To develop commercial reactors, the AEC's program had two main thrusts: to develop basic R&D and to build demonstration plants in partnership with industry. Prior to the late 1960s, the AEC's goal was commercialization of LWR technology.

Through the 1970s the major federal incentive for nuclear energy was the AEC Civilian Reactor Development Program. Approximately 81 percent of the R&D funds allocated to nuclear energy by the federal government from 1950 to 1978 was spent through CRDP, and the remaining 19 percent was disbursed through other program categories.

Developmental fission reactors and the early cooperative power reactor projects were also supported through the CRDP program. From the late 1960s through the early 1980s, the liquid metal fast breeder reactor program received substantial funding, especially the Clinch River Breeder reactor before its construction was canceled in 1983. A DOE-funded study by Battelle

Pacific Northwest Laboratory estimated that, through 1975, federal expenditures for commercial nuclear energy R&D totaled $38.9 billion (2006 dollars)[10].

The following series of tables reveals how R&D expenditures were broken out in the AEC budget from 1950 to 1975. Because the breakouts vary, it is not feasible to present the data in one continuous table with a consistent set of line items across the entire 25-year period.

Exhibit 13 shows AEC nuclear reactor R&D expenditures for the period, 1950–1962. It illustrates that, during the early years of the AEC nuclear research program, $24 billion was spent on nuclear reactor R&D, but only $2.1 billion (9 percent) of these funds were expended on LWR research.

[10] See Bruce W. Cone, et. al., "An Analysis of Federal Incentives Used to Stimulate Energy Production," Richland, Washington: Battelle Pacific Northwest Laboratory, 1980, Chapter IV.

## Exhibit 13 – Nuclear Reactor Research and Development Expenditures, 1950–1962
**(Millions of 2006 Dollars)**

| PROGRAM | EXPENDITURES |
|---|---|
| Civilian Nuclear Power Reactors | 4,867 |
| Light Water Reactors | |
| Pressurized Light Water | 1,511 |
| Boiling Light Water | 544 |
| Heavy Water | 319 |
| Organic Moderated | 378 |
| Gas Cooled | 577 |
| Sodium Cooled | 1,478 |
| Other Studies and Development | 59 |
| Army Reactors | 465 |
| Naval Reactors | 6,523 |
| Merchant Ship Reactors | 284 |
| Missile and Space Propulsion | 1,565 |
| Aircraft Propulsion | 3,130 |
| Auxiliary Power Sources | 656 |
| General | 6,504 |
| TOTAL | 23,995 |

Exhibit 14 tells a similar story for AEC expenditures for the years 1963–1975. As summarized in Exhibit 15, the AEC expenditures focused on two major program thrusts of the federal nuclear energy R&D program: the LWR program and the breeder program. Once again, reactor R&D expenditures are a small portion of the total AEC budget ($31.2 billion out of $151 billion—about 21 percent), and expenditures for light water reactor research were a small portion of reactor R&D funds—$1.4 billion out of $31.2 billion, about 4.5 percent. These later data illustrate that, based on policy decisions made during the early 1960s, the AEC reactor development research program increasingly emphasized the breeder reactor. This emphasis resulted from major AEC policy decisions in the early 1960s to concentrate on breeder reactor development based on estimated long-term scarcity of uranium to fuel LWRs. Between 1963 and 1975, nearly 25 percent of all reactor R&D funds were devoted to the breeder program—$7.6 billion out of $31.2 billion. By the early 1970s, the breeder research program was clearly dominant, accounting for nearly half of all reactor R&D funds, and the light water reactor program was negligible.

## Exhibit 14 – Summary of U.S. AEC Expenditures by Major Program, 1963–1975

**(Millions of constant 2006 dollars)**

| | FY63 | FY64 | FY65 | FY66 | FY67 | FY68 | FY69 | FY70 | FY71 | FY72 | FY73 | FY74 | FY75 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nuclear Materials** | 6,325 | 5,312 | 4,500 | 3,939 | 3,482 | 3,087 | 2,779 | 2,373 | 2,164 | 2,161 | 2,257 | 2,351 | 1,274 | 42,003 |
| **Weapons Development** | 3,902 | 4,435 | 4,127 | 3,839 | 3,751 | 3,828 | 4,188 | 3,981 | 3,963 | 3,885 | 3,728 | 3,316 | 1,742 | 48,685 |
| **Development of Nuclear Reactors** | 2,846 | 3,106 | 2,910 | 2,574 | 2,693 | 2,680 | 2,370 | 2,281 | 2,178 | 2,113 | 2,127 | 2,060 | 1,233 | 31,171 |
| **LWRs** | 175 | 243 | 201 | 164 | 179 | 117 | 93 | 67 | 51 | 52 | 31 | 11 | 7 | 1388 |
| **Breeder Reactors** | 112 | 270 | 400 | 443 | 510 | 663 | 602 | 567 | 590 | 711 | 960 | 876 | 857 | 7558 |
| **All Other Reactors** | 2,559 | 2,593 | 2,309 | 1,968 | 2,004 | 1,900 | 1,675 | 1.647 | 1,537 | 1,349 | 1,137 | 1,179 | 369 | 22,225 |
| **Physical Research** | 1,115 | 1,191 | 1,283 | 1,394 | 1,489 | 1,514 | 1,548 | 1,488 | 1,381 | 1,155 | 1,308 | 1,320 | 584 | 16,768 |
| **Biomedical and Environmental Research** | 398 | 424 | 459 | 479 | 484 | 483 | 461 | 479 | 446 | 448 | 473 | 497 | 304 | 5,838 |
| **Administration, Regulation and Misc.** | 604 | 639 | 623 | 611 | 577 | 649 | 620 | 488 | 400 | 641 | 345 | 85 | 324 | 6,605 |
| **Total Cost of Operations** | 15,189 | 15,108 | 13,902 | 12,836 | 12,476 | 12,241 | 11,966 | 11,089 | 10,532 | 10,403 | 10,237 | 9,629 | 5,460 | 151,069 |

## Exhibit 15 – Summary of Federal R&D Expenditures for Nuclear Energy, 1950–2006

**(Billions of 2006 dollars)**

| | 1950–1975 | 1976–2006 | Total 1950–2006 |
|---|---|---|---|
| **Light Water Reactor R&D** | 3.5 | 1.8 | 5.3 |
| **Breeder R&D** | 9.2 | 14.5 | 23.7 |
| **Other Nuclear Energy R&D** | 26.2 | 11.8 | 38.0 |
| **Total** | 38.9 | 28.1 | 67.0 |

Exhibit 16 shows the components of the ERDA/DOE nuclear energy R&D program for the years 1976-1997; Exhibit 17 shows federal nuclear energy R&D expenditures for 1998–2003; and Exhibit 18 shows federal nuclear energy R&D expenditures for 2004–2006. The authors estimate that the federal government spent $66.8 billion (2006 dollars) on commercial nuclear energy R&D through 2006 (Exhibits 13–18). These figures include R&D contributions from programs directly supportive of nuclear energy as an electricity generation source. Funds also were expended for the breeder program (including Clinch River), development of facilities such as the Fast Flux Test Reactor and basic R&D.

The data primarily reflects R&D expenditures on nondefense-related programs, including advanced light water reactors and other reactor technologies. The R&D expenditures for supporting technologies (waste management and reactor safety research) also are included, as are research funds for advanced radioisotope power systems, facilities, space reactor power systems and related programs. Expenditures for the fusion program are not included, as fusion represents a distinct technology with little direct application to current commercial nuclear energy.

In deriving these estimates, it was assumed that the military nuclear programs contributed technological information to the commercial nuclear energy program in an amount about equal to that which the military programs received from the commercial program. The one exception to this is the submarine propulsion program, which made significant technological and personnel contributions in the 1950s to industry LWR programs. Although much of the program was classified, the transfer of personnel from the naval program to industry carried both the expertise and technology into the industry development programs. Important contributions from the submarine program include zirconium technology, reactor control (including nuclear constants and codes), piping and pressure vessel design.

## Exhibit 16 – Federal R&D Expenditures for Nuclear Energy, by Major Program, 1976–1997

**(Millions of constant 2006 dollars)**

| | FY76 | 76tq | FY77 | FY78 | FY79 | FY80 | FY81 | FY82 | FY83 | FY84 | FY85 | FY86 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nuclear Energy R&D** | 1,884 | 572 | 2,538 | 2,836 | 2,789 | 2,514 | 2,346 | 2,308 | 1,519 | 1,211 | 724 | 635 |
| **Commercial Nuclear Waste** | 101 | 55 | 333 | 333 | 477 | 503 | 618 | 462 | 79 | 47 | --- | --- |
| **Spent Nuclear Fuel** | --- | --- | --- | 13 | 27 | 27 | 46 | --- | --- | --- | --- | --- |
| **Converter Reactor Systems** | 139 | 70 | 194 | 259 | 299 | 148 | 141 | 201 | 147 | 167 | 277 | 81 |
| **Light Water Reactor** | 7 | 10 | 29 | 35 | 60 | 67 | 88 | 105 | 72 | 97 | 88 | 81 |
| **Other Converter Reactor Systems** | 132 | 60 | 165 | 224 | 239 | 82 | 52 | 96 | 75 | 70 | 189 | --- |
| **Advanced Nuclear System** | 120 | 36 | 121 | 165 | 136 | 89 | 94 | 83 | 72 | 60 | 48 | 214 |
| **Facilities**[11] | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 223 |
| **Advanced Radioisotope Power System** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 34 |
| **Space Reactor Power System** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 34 |
| **Nuclear Fuel Cycle** | --- | --- | --- | --- | --- | --- | --- | 113 | 80 | --- | --- | --- |
| **Breeder Program** | 1,524 | 411 | 1,890 | 2,067 | 1,850 | 1,715 | 1,447 | 1,369 | 1,025 | 759 | 344 | 33 |
| **Remedial Action** | --- | --- | --- | --- | --- | --- | --- | 80 | 117 | 178 | --- | --- |
| **University Reactor Fuel Asst. & Support** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Advanced Test Reactor Fusion Irradiation** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Program Direction** | --- | --- | --- | --- | --- | 32 | --- | --- | --- | --- | 52 | 17 |
| **Policy Management & Misc.** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 3 | --- |
| **Civilian Waste R&D** | --- | --- | --- | --- | --- | --- | --- | --- | --- | 20 | 45 | 26 |
| **Total Nuclear Energy Supply R&D** | 1,884 | 572 | 2,538 | 2,836 | 2,789 | 2,514 | 2,346 | 2,308 | 1,519 | 1,230 | 769 | 661 |

[11] Includes Oak Ridge and Test Area Reactor Management.

## Exhibit 16 – Federal R&D Expenditures for Nuclear Energy, by Major Program, 1976–1997

**(Millions of constant 2006 dollars)**

| | FY87 | FY88 | FY89 | FY90 | FY91 | FY92 | FY93 | FY94 | FY95 | FY96 | FY97 | Total 76–97 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nuclear Energy R&D** | 537 | 552 | 538 | 497 | 428 | 444 | 457 | 304 | 284 | 182 | 157 | 26,255 |
| **Commercial Nuclear Waste** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 3,007 |
| **Spent Nuclear Fuel** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 113 |
| **Converter Reactor Systems** | 56 | 51 | 44 | 35 | 53 | 86 | 79 | 75 | 80 | 48 | 45 | 2,773 |
| **Light Water Reactor** | 56 | 51 | 44 | 35 | 53 | 86 | 79 | 75 | 80 | 48 | 45 | 1,390 |
| **Other Converter Reactor Systems** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1,383 |
| **Advanced Nuclear System** | 123 | 147 | 116 | 86 | 80 | 80 | 80 | 55 | 51 | 32 | 23 | 2,109 |
| **Facilities *** | 209 | 188 | 208 | 248 | 130 | 133 | 124 | 41 | 32 | 20 | 17 | 1,573 |
| **Advanced Radioisotope Power System** | 34 | 33 | 58 | 71 | 105 | 69 | 71 | 69 | 76 | 59 | 45 | 722 |
| **Space Reactor Power System** | 79 | 119 | 100 | 45 | 46 | 55 | 40 | 35 | 1 | --- | --- | 553 |
| **Nuclear Fuel Cycle** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 193 |
| **Breeder Program** | 23 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 14,456 |
| **Remedial Action** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 374 |
| **University Reactor Fuel Asst. & Support** | --- | --- | --- | --- | --- | --- | --- | --- | 4 | 3 | 4 | 12 |
| **Advanced Test Reactor Fusion Irradiation** | --- | --- | --- | --- | --- | --- | --- | --- | 3 | 2 | 1 | 7 |
| **Program Direction** | 13 | 14 | 12 | 13 | 14 | 22 | 19 | 14 | 17 | 9 | 11 | 260 |
| **Policy Management & Misc.** | --- | --- | --- | --- | --- | --- | 45 | 15 | 19 | 10 | 11 | 103 |
| **Civilian Waste R&D** | 11 | 9 | 3 | 1 | 1 | 8 | 7 | 1 | 1 | --- | --- | 132 |
| **Total Nuclear Energy Supply R&D** | 548 | 561 | 541 | 498 | 429 | 452 | 464 | 305 | 285 | 182 | 157 | 26,387 |

## Exhibit 17 – Federal R&D Expenditures for Nuclear Energy, by Major Program, 1998–2003

**(Millions of constant 2006 dollars)**

| | FY98 | FY99 | FY00 | FY01 | FY02 | FY03 | Total 98-03 |
|---|---|---|---|---|---|---|---|
| University Reactor Infrastructure and Education Assistance | 9 | 13 | 14 | 13 | 20 | 20 | 89 |
| Nuclear Energy Plant Optimization | --- | --- | 5 | 5 | 7 | 5 | 22 |
| Nuclear Energy Research Initiative | --- | 22 | 25 | 31 | 24 | 19 | 121 |
| International Nuclear Energy Research Initiative | --- | --- | --- | 8 | 10 | 7 | 25 |
| Next Generation Nuclear Plant | --- | --- | --- | --- | --- | 3 | 3 |
| Generation IV R&D | --- | --- | --- | 4 | 4 | 9 | 17 |
| Nuclear Power 2010 | --- | --- | --- | 3 | 9 | 35 | 47 |
| Civilian R&D (ATW) | --- | --- | 9 | --- | --- | --- | 9 |
| Nuclear Hydrogen Initiative | --- | --- | --- | --- | --- | 2 | 2 |
| Isotope Support | 23 | 26 | 22 | --- | --- | --- | 71 |
| Advanced Radioisotope Power Systems | 48 | 44 | 34 | --- | --- | --- | --- |
| Advanced Nuclear Medicine Initiative | --- | --- | --- | 3 | --- | --- | --- |
| Advanced Fuel Cycle Initiative | --- | --- | --- | --- | 86 | 62 | 148 |
| Test Reactor Area Landlord | 9 | 9 | --- | --- | --- | --- | --- |
| Program Direction | 9 | 11 | 12 | 5 | 13 | 14 | 64 |
| Total DOE Nuclear Energy Supply R&D | 98 | 125 | 121 | 72 | 173 | 176 | 765 |

## Exhibit 18 – Federal R&D Expenditures for Nuclear Energy, 2004–2006

**(Millions of constant 2006 dollars)**

| | FY04 | FY05 | FY06 | Total 04-06 |
|---|---|---|---|---|
| University Reactor Infrastructure and Education Assistance | 24 | 25 | 24 | 73 |
| Nuclear Energy Plant Optimization | 3 | 3 | 0 | 6 |
| Nuclear Energy Research Initiative | 6 | 3 | 0 | 9 |
| Generation IV R&D | 29 | 41 | 45 | 115 |
| Nuclear Power 2010 | 20 | 52 | 56 | 128 |
| Nuclear Hydrogen Initiative | 6 | 9 | 20 | 35 |
| Advanced Nuclear Medicine Initiative | 139 | 128 | 14 | 281 |
| Advanced Fuel Cycle Initiative | 70 | 70 | 70 | 210 |
| Program Direction | 20 | 21 | 11 | 52 |
| Total DOE Nuclear Energy Supply R&D | 317 | 352 | 240 | 909 |

The financial contribution from the submarine propulsion R&D programs was assumed to be 50 percent of the total spending on submarine propulsion R&D programs in 1950, declining linearly to zero in 1959. The resultant contribution of the nuclear submarine program to the commercial nuclear energy R&D program was approximately $400 million (2006 dollars).

There is no simple way to prove the important assumption about the relationship between the defense and civilian nuclear research programs. In the early years of the nuclear energy program, the weapons programs developed many aspects of the emerging commercial nuclear power program. Methods of handling radio-active materials, neutron diffusion codes, critical experiment technology and other information were largely applicable to the commercial program.

However, the commercial program developed around an alternative fuel form (uranium oxide rather than uranium metal), cladding material, pressure barrier (vessel rather than tube), moderator (light water instead of graphite or heavy water), and reactor components. Technology from these developments became available to the weapons program. Fuel reprocessing technology, as then conceived for commercial nuclear power, was based on weapons program-developed processes, but it was not envisioned that these processes would become commercial. Waste management technology was being developed for both applications.

The LWR technology grew out of the military reactor program. However, fuel forms differ and reactor components are substantially larger and of different designs for the commercial market. Compactness and long-life are much more important to military applications. Further, much of the military technology was classified, though most of the commercial technology was reported in open literature and was thus available for military application.

Nevertheless, the civilian power reactor program was strongly influenced by and benefited from the military programs. For example, the choice of a pressurized water reactor system over the other systems stems from the specific industry experience with this reactor type as part of the military program. Second, the availability of excess enrichment capacity made it economic to select the LWR option, rather than a graphite-moderated, gas-cooled natural uranium system. Third, the nuclear infrastructure, industry, universities, and national laboratories existed because of military programs. Finally, civilian reactor research could be carried out in laboratories staffed and equipped through military programs at the marginal cost of the research.

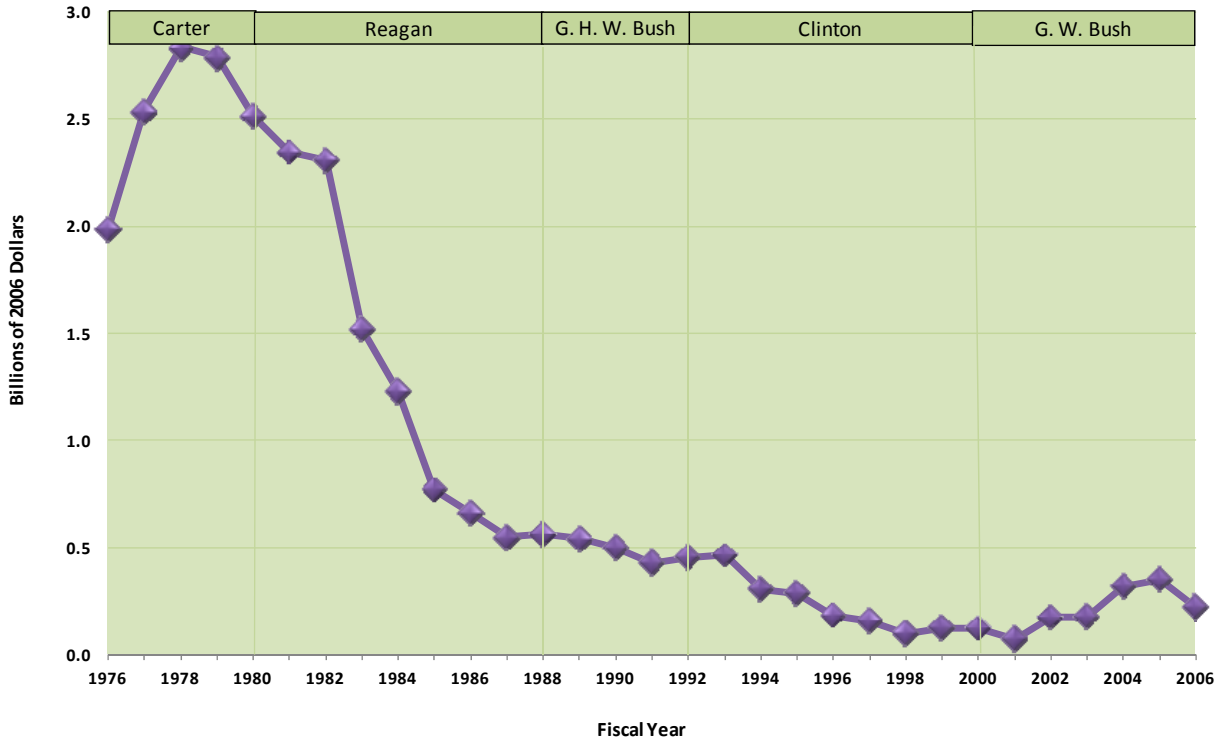
## D. Major Findings

Focusing primarily on the period 1976–2006, the authors find:

- The commercial nuclear energy R&D program peaked at $2.8 billion in 1978 and declined steadily thereafter, reaching a low of $75 million in 2001. The trend in federal spending on nuclear energy R&D is shown in Exhibit 19.
- Since 1976, only 6 percent of the total of $28 billion in nuclear energy R&D expenditures has been devoted to LWRs.

- Of the total nuclear R&D expenditures over this period, more than half, 52 percent ($14.5 billion), were devoted to the breeder program. Since 1950 the breeder program consumed 35 percent—$23.7 billion of $67 billion—of civilian nuclear energy R&D, and over half of the funds expended since 1976.
- The light water reactor program always has been a small portion of nuclear energy research, accounting for only $5.3 billion (8 percent) of the $67 billion total R&D expenditures. Nevertheless, light water technology currently supplies 20 percent of the nation's electricity.
- From the early 1970s through the mid-1980s, the breeder program dominated all other nuclear energy research programs, accounting for well over half of the R&D funding.

**Exhibit 19 – Federal Nuclear R&D Timeline, 1976–2006**



# Appendix 7 – Coal R&D Expenditures

## A. Background

The U.S. has relied on coal as a major energy source for years, and it currently provides about half of the nation's electricity and about one-quarter of its total energy supply. Nevertheless, for many years the coal industry operated at relatively low earnings compared to other major U.S. industries. In addition, the industry lacked the highly specialized multi-disciplinary laboratories and skills required for effective research.

Over the past five decades, the federal government has funded a substantial coal research program, including R&D for coal production, resource assessment, mining techniques, mining health and safety, coal utilization, and pollution control and abatement. This research has been conducted at the Bureau of Mines of the U.S. Department of the Interior, the EPA, ERDA and DOE.

From the 1940s through 1996 (when it was abolished), the BOM conducted extensive R&D pertaining to coal mining, preparation and utilization and coking coal characteristics. This research included mining methods and systems, mechanization of operations, coal cleaning processes, and factors to increase the productivity of mines, as well as experiments in longwall mining, the use of diamond drills and the development of roof bolting. For many years, the BOM made field and laboratory examinations and analyses of the chemical constituents of coal on a mine-by-mine basis and regularly published reports on them. In addition, the BOM developed improved coal treatment technologies to upgrade the quality of coal by reducing the amount of ash, sulfur and other coal constituents.

The major growth market for coal (aside from exports) is the electric utility industry, which is continually expanding to meet increased requirements for electric power. Among the major factors limiting the use of coal are environmental regulations, particularly air pollution standards, which prescribe limits on particulates, sulfur dioxide, nitrogen oxide and other coal residuals.

Extensive research is underway within federal agencies to provide viable anti-pollutant processes, including different types of scrubbers, fluidized bed combustion, solvent refining and other processes. This includes expenditures by the Environmental Protection Agency—in addition to those expended by the BOM and DOE—for research to mitigate the environmental impact of using coal as a fuel, especially for electricity generation.

In addition to research and development on coal combustion techniques, DOE has engaged in extensive research on coal gasification, coal liquefaction, pulverized coal combustion, carbon sequestration and solvent refining. Considerable research also has been conducted by both the federal government and industry on the preparation of coal to reduce impurities, including sulfur, as an alternative to post-combustion abatement. Research on new uses of coal, including low-rank coals such as lignite, has been conducted for many years.

The residual content of coal has become an increasingly important factor in the production and utilization of coal, as has the relative heating values (Btu) of coals, both in their direct relation to environmental regulations and their costs. Generally, coals of high Btu value command the highest prices.

## B. The Coal Research Program

Coal R&D includes a wide variety of technologies for promoting the use of coal in an environmentally responsible manner, recognizing the expected increase in U.S. coal consumption in coming decades. The objective of this program has been to conduct research necessary to strengthen the scientific and engineering technology base on which industry can draw in developing new products and processes. The program funds generic and technology-based research and development and environmental research. It supports experimental facilities with unique capabilities and includes pilot plants and test facilities where operation results in net revenues to the federal government. The research program provides for a limited federal role in support of longer-term, high-risk R&D conducted at universities, national labs and the Energy Technology Centers, as well at private sector firms. Today, the coal program includes the Coal Research Initiative (which includes the Clean Coal Power Initiative, FutureGen and the core coal R&D program) and fuel cells.

The Clean Coal Power Initiative (CCPI), started in 2002[12], is a cooperative, cost-shared program between the government and industry to demonstrate emerging technologies in coal-based power generation to help accelerate their commercialization. The nation's power generators, equipment manufacturers and coal producers help identify the most critical barriers to coal's use in the power sector. Technologies will be selected with the goal of accelerating development and deployment of coal technologies that will economically meet environmental standards while increasing the efficiency and reliability of coal power plants.

The FutureGen project, started in 2003, was intended to establish the capability and feasibility of co-producing electricity and hydrogen from coal with near-zero atmospheric emissions, including those from carbon. It planned to employ a public/private partnership to demonstrate technology, ultimately leading to near-zero atmospheric emission plants (including carbon) that are fuel-flexible and capable of multiproduct output and electrical efficiencies over 60 percent. The FutureGen-type plants were originally expected to produce electricity at prices no more than 10 percent above that of comparable plants that do not use carbon sequestration, such as coal, biomass or petroleum coke.

The advanced coal R&D effort focuses on all the key technologies needed for FutureGen, such as carbon sequestration, membrane technologies for oxygen and hydrogen separation, advanced turbines, fuel cells, coal-to-hydrogen conversion gasifier-related technologies, and other technologies. Some CCPI activities complement FutureGen and will help drive down the costs of Integrated Gasification Combined Cycle (IGCC) systems and other technologies for near-zero atmospheric emission plants.

The fuels and power systems program provides important research for FutureGen to reduce dramatically coal power plant emissions (especially mercury) and significantly improve efficiency to reduce carbon emissions, leading to a viable near-zero atmospheric emissions coal energy system.

[12] See *http://www.netl.doe.gov/publications/factsheets/program/Prog052.pdf*.

The Innovations for Existing Plants program has a near- to mid-term focus on improving overall power plant efficiency and developing advanced cost-effective environmental control technologies, with a focus on mercury, for retrofitting existing power plants and other coal technologies, including those developed in support of the FutureGen project.

The IGCC program will continue to develop technologies for gas stream purification to meet quality requirements for use with fuel cells and conversion processes, impurity tolerant hydrogen separation technology; to enhance process efficiency; and to reduce costs and energy requirements for producing oxygen using advanced technologies such as membranes.

The advanced turbines program is focused on creating the technology base for turbines that will permit the design of near-zero atmospheric emission IGCC plants and a class of FutureGen plants with carbon capture and sequestration. Program research focuses on developing enabling technology for high-efficiency hydrogen and syngas turbines for advanced gasification systems that will permit the design of near-zero atmospheric emission FutureGen plants with carbon capture and sequestration.

The carbon sequestration program is developing a portfolio of technologies that reduce greenhouse gas emissions. The program focuses primarily on developing capture and separation technologies that dramatically lower the costs and energy requirements for reducing carbon dioxide emissions from fossil-based (especially coal) energy plants. The program goal is to research and develop a portfolio of safe and cost-effective greenhouse gas capture, storage and mitigation technologies by 2012, leading to substantial market penetration beyond 2012.

The mission of the fuels program is to conduct the research necessary to promote the transition to a hydrogen economy. Research targets cost reduction and increased efficiency of hydrogen production from coal feed stocks as part of the Hydrogen Fuel Initiative and in support of the FutureGen project.

Advanced research projects seek a greater understanding of the physical, chemical, biological and thermodynamic barriers that limit the use of coal and other fossil fuels. The program funds two categories of activity. The first includes applied research programs to develop the technology base needed for the development of super-clean, very-high efficiency coal-based power and coal-based fuel systems. The second is a set of crosscutting studies and assessment activities in environmental, technical, and economic analyses, coal technology export, and integrated program support.

The objectives of the fuel cells activity are to provide the technology-based development of low-cost, scalable and fuel flexible fuel cell systems that can operate in central coal-based power systems, as well as to have applications in other electric utility (both central and distributed), industrial and commercial/residential markets.

The major program components supported since 1976 include:

- gasification combined cycle
- pressurized fluid bed
- fuel cells
- carbon capture and sequestration
- transportation fuels and chemicals
- control technology and coal preparation
- advanced research and technology development
- coal liquefaction
- combustion systems
- heat engines
- magnetohydrodynamics
- surface coal gasification
- underground coal gasification
- mining R&D
- advanced environmental control technology
- FutureGen
- Clean Coal Power Initiative
- program direction and management support
- miscellaneous coal R&D
- coal research at EPA
- coal research at the BOM.

## C. Federal Coal R&D Expenditures

As discussed, coal research programs supported by the federal government between 1950 and 1975 were conducted within the BOM and, since the early 1970s, also within EPA. These expenditures are shown in Exhibit 20, which illustrates that, over the 26-year period, the federal government invested $5.2 billion in coal R&D programs. Coal R&D was relatively constant in real terms during the 1950s, increased gradually between 1960 and 1968, and then increased more than eightfold between 1969 and 1975.

### Exhibit 20 – Summary of Federal R&D Expenditures for Coal, 1950–1975

**(Millions of 2006 dollars)**

| Year | Expenditures | Year | Expenditures |
|---|---|---|---|
| **1950** | 86 | **1963** | 103 |
| **1951** | 81 | **1964** | 107 |
| **1952** | 81 | **1965** | 98 |
| **1953** | 80 | **1966** | 109 |
| **1954** | 63 | **1967** | 128 |
| **1955** | 52 | **1968** | 155 |
| **1956** | 57 | **1969** | 141 |
| **1957** | 62 | **1970** | 167 |
| **1958** | 74 | **1971** | 279 |
| **1959** | 72 | **1972** | 404 |
| **1960** | 86 | **1973** | 604 |
| **1961** | 101 | **1974** | 838 |
| **1962** | 100 | **1975** | 1,143 |

Exhibits 21 through 25 show the detailed federal coal R&D programs undertaken at ERDA, DOE, EPA and the BOM between 1976 and 2006. Over this period, coal R&D expenditures totaled more than $26 billion, as summarized in Exhibit 26. They increased rapidly from 1976 through 1980, reaching an all-time high of $2.3 billion in 1980, as shown in Exhibit 27. Expenditures decreased slightly to $2.1 billion in 1981, and then decreased drastically, falling by nearly three-quarters to $590 million by 1984. Thereafter, coal R&D expenditures remained relatively constant until 1990 and then decreased gradually thereafter, declining to $274 million in 1997—at which time they were, in real terms, only 12 percent of their 1980 total. However, by 2001, coal R&D funding had increased to $838 million — the highest level in two decades. In 2006, coal R&D expenditures totaled $538 million.

## Exhibit 21 – Federal R&D Expenditures for Coal, by Major Program, 1976–1988

**(Millions of constant 2006 dollars)**

| | FY76 | 76tq | FY 77 | FY78 | FY79 | FY80 | FY81 | FY82 | FY83 | FY84 | FY85 | FY86 | FY87 | FY88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U.S. DOE** | 1,010 | 260 | 1,354 | 1,562 | 1,739 | 1,788 | 1,657 | 929 | 442 | 376 | 401 | 389 | 322 | 350 |
| **Control Technology & Coal Preparation** | -- | -- | -- | -- | -- | -- | -- | 48 | 52 | 47 | 62 | 55 | 62 | 70 |
| **Advanced Research & Technology Development** | 108 | 27 | 127 | 135 | 115 | 139 | 104 | 109 | 68 | 70 | 70 | 56 | 52 | 40 |
| **Coal Liquefaction** | 301 | 79 | 321 | 300 | 514 | 490 | 690 | 445 | 71 | 52 | 45 | 55 | 40 | 43 |
| **Combustion Systems** | 142 | 43 | 161 | 183 | 147 | 171 | 127 | 80 | 45 | 33 | 52 | 48 | 24 | 40 |
| **Heat Engines** | -- | -- | -- | -- | 145 | 144 | 94 | 29 | 10 | 12 | 21 | 21 | 20 | 29 |
| **Magnetohydrodynamics** | 104 | 27 | 116 | 194 | 149 | 185 | 167 | 55 | 55 | 55 | 53 | 47 | 45 | 56 |
| **Surface Coal Gasification** | 239 | 48 | 413 | 569 | 399 | 389 | 226 | 104 | 72 | 68 | 56 | 69 | 41 | 36 |
| **Underground Coal Gasification** | -- | -- | -- | -- | 37 | 23 | 21 | 15 | 11 | 11 | 13 | 8 | 3 | 4 |
| **Mining Research & Development** | -- | -- | 149 | 167 | 190 | 154 | 89 | 22 | -- | -- | -- | -- | -- | -- |
| **Advanced Environmental Control Tech** | -- | -- | -- | -- | 17 | 55 | 104 | -- | -- | -- | -- | -- | -- | -- |
| **Program Direction & Management Support** | -- | -- | -- | -- | 25 | 27 | 25 | 23 | 59 | 29 | 29 | 33 | 34 | 32 |
| **Miscellaneous** | 117 | 36 | 67 | 13 | -- | 11 | 11 | -- | -- | -- | -- | -- | -- | -- |
| **U.S. EPA** | 217 | 70 | 347 | 322 | 332 | 354 | 351 | 168 | 97 | 113 | 145 | 141 | 143 | 139 |
| **Bureau of Mines** | 205 | 48 | 237 | 254 | 194 | 154 | 120 | 92 | 72 | 100 | 76 | 65 | 77 | 75 |
| **Total Coal Energy R&D** | 1,432 | 377 | 1,937 | 2,138 | 2,264 | 2,296 | 2,128 | 1,189 | 611 | 590 | 623 | 596 | 542 | 564 |

## Exhibit 22 – Federal R&D Expenditures for Coal, by Major Program, 1989–1997

**(Millions of constant 2006 dollars)**

| | FY89 | FY90 | FY91 | FY92 | FY93 | FY94 | FY95 | FY96 | FY97 | Total 76-97 |
|---|---|---|---|---|---|---|---|---|---|---|
| **U.S. DOE** | 365 | 377 | 377 | 339 | 280 | 247 | 205 | 228 | 146 | 15,144 |
| **Control Tech & Coal Preparation** | 75 | 85 | 79 | 69 | 57 | 59 | 52 | 43 | 36 | 950 |
| **Advanced Research & Tech Devel.** | 40 | 37 | 44 | 41 | 36 | 37 | 31 | 25 | 21 | 1,530 |
| **Coal Liquefaction** | 48 | 51 | 60 | 53 | 49 | 33 | 33 | 19 | 12 | 3,802 |
| **Combustion Systems** | 41 | 48 | 52 | 52 | 49 | 59 | 53 | 53 | 38 | 1,743 |
| **Heat Engines** | 35 | 31 | 34 | 24 | 4 | -- | -- | -- | -- | 652 |
| **Magnetohydrodynamics** | 57 | 58 | 56 | 55 | 40 | 7 | -- | -- | -- | 1,578 |
| **Surface Coal Gasification** | 34 | 34 | 21 | 14 | 14 | 21 | 13 | 10 | 9 | 2,898 |
| **Underground Coal Gasification** | 1 | 1 | 1 | -- | -- | -- | -- | -- | -- | 149 |
| **Mining Research & Development** | -- | -- | -- | -- | -- | -- | -- | 55 | 7 | 832 |
| **Advanced Env Control Tech** | -- | -- | -- | -- | -- | -- | -- | -- | -- | 176 |
| **Program Direction & Mgt. Support** | 34 | 33 | 32 | 31 | 31 | 32 | 23 | 24 | 24 | 578 |
| **Miscellaneous** | -- | -- | -- | -- | -- | -- | -- | -- | -- | 254 |
| **U.S. EPA** | 131 | 120 | 113 | 128 | 127 | 119 | 105 | 157 | 128 | 4,065 |
| **Bureau of Mines** | 81 | 79 | 81 | 79 | 77 | 81 | 75 | 4 | -- | 2,327 |
| **Total Coal Energy R&D** | 577 | 576 | 572 | 545 | 484 | 446 | 385 | 389 | 274 | 21,537 |

## Exhibit 23 – Federal Coal R&D, 1998–2000

**(Millions of constant 2006 dollars)**

| | FY98 | FY99 | FY00 | Total 98–00 |
|---|---|---|---|---|
| U.S. DOE | 216 | 246 | 242 | 704 |
| Advanced Electric Power Systems | 83 | 104 | 91 | 278 |
| Advanced Pulverized Coal Technology | 20 | 17 | 2 | 39 |
| Indirectly Fired Cycle | 5 | 9 | 8 | 22 |
| Gasification Combined Cycle | 26 | 38 | 40 | 104 |
| Pressurized Fluid Bed | 22 | 17 | 14 | 53 |
| Advanced Research and Environmental | 15 | 23 | 27 | 65 |
| Advanced Clean Fuel Research | 18 | 19 | 22 | 59 |
| Coal Preparation | 5 | 5 | 4 | 14 |
| Coal Liquefaction | 8 | 11 | 8 | 27 |
| Steelmaking Feedstock | 4 | --- | 8 | 8 |
| Advanced Research and Environmental | 1 | 2 | 2 | 5 |
| Advanced Research and Tech Development | 22 | 24 | 26 | 72 |
| Fuel Cells | 48 | 52 | 52 | 152 |
| Miscellaneous R&D | 8 | 8 | 7 | 23 |
| Program Direction and Management Support | 37 | 39 | 44 | 120 |
| U.S. EPA Coal R&D | 134 | 138 | 117 | 389 |
| Total Federal Coal R&D | 350 | 384 | 359 | 1,093 |

## Exhibit 24 – Federal Coal R&D, 2001–2003

**(Millions of constant 2006 dollars)**

| | FY01 | FY02 | FY03 | Total 01–03 |
|---|---|---|---|---|
| U.S. DOE | 444 | 526 | 526 | 1,496 |
| Clean Coal Power Initiative | --- | 162 | 159 | 321 |
| Central Systems | 226 | 104 | 101 | 431 |
| Innovations for Existing Plants | 23 | 25 | 24 | 72 |
| Advanced Systems | | | | |
| Integrated Gasification Combined Cycle | 47 | 47 | 47 | 141 |
| Pressurized Fluidized Bed | 13 | 12 | 11 | 36 |
| Turbines | 35 | 20 | 19 | 74 |
| Power Plant Improvement Initiative | 108 | --- | --- | 108 |
| Sequestration | 22 | 35 | 43 | 100 |
| Fuels | 26 | 37 | 33 | 96 |
| Transportation Fuels and Chemicals | 9 | 28 | 23 | 60 |
| Solid Fuels and Feed stocks | 4 | 5 | 7 | 16 |
| Advanced Fuels Research | 5 | 4 | 3 | 12 |
| Steelmaking | 8 | --- | --- | 8 |
| Advanced Research | 33 | 34 | 35 | 102 |
| Coal Utilization Science | 7 | 7 | 10 | 24 |
| Materials | 8 | 8 | 10 | 26 |
| Technology Crosscut | 14 | 12 | 12 | 38 |
| Other Advanced Research | 4 | 7 | 3 | 14 |
| Fuel Cells | 60 | 63 | 64 | 187 |
| Miscellaneous R&D | 11 | 16 | 16 | 43 |
| Program Direction and Management Support | 66 | 75 | 76 | 217 |
| U.S. EPA Coal R&D | 111 | 110 | 100 | 321 |
| Total Federal Coal R&D | 555 | 636 | 626 | 1,817 |

### Exhibit 25 – Federal Coal R&D, 2004–2006
**(Millions of constant 2006 dollars)**

| | FY04 | FY05 | FY06 | Total 04–06 |
|---|---|---|---|---|
| **U.S. DOE** | 578 | 436 | 451 | 1,465 |
| **Clean Coal Power Initiative** | 181 | 49 | 50 | 280 |
| **Central Systems** | 96 | 81 | 99 | 276 |
| **Sequestration** | 43 | 45 | 67 | 155 |
| **Fuels** | 33 | 32 | 29 | 94 |
| **Advanced Research** | 40 | 43 | 38 | 121 |
| **Fuel Cells** | 73 | 77 | 62 | 212 |
| **Program Direction and Management Support** | 112 | 109 | 106 | 327 |
| **U.S. EPA Coal R&D** | 99 | 90 | 87 | 276 |
| **Total Federal Coal R&D** | 677 | 526 | 538 | 1,741 |

### Exhibit 26 – Federal Coal R&D, 1976–2006
**(Millions of constant 2006 dollars)**

| | 76–97 | 98–00 | 01–03 | 04–06 | Total |
|---|---|---|---|---|---|
| **U.S. DOE** | 15,144 | 704 | 1,496 | 1,465 | 18,809 |
| **U.S. EPA Coal R&D** | 4,065 | 389 | 321 | 276 | 5,051 |
| **BOM** | 2,327 | | | | 2,327 |
| **Total Federal Coal R&D** | 21,536 | 1,093 | 1,817 | 1,741 | 26,187 |

Note: The BOM ceased operations in 1996.

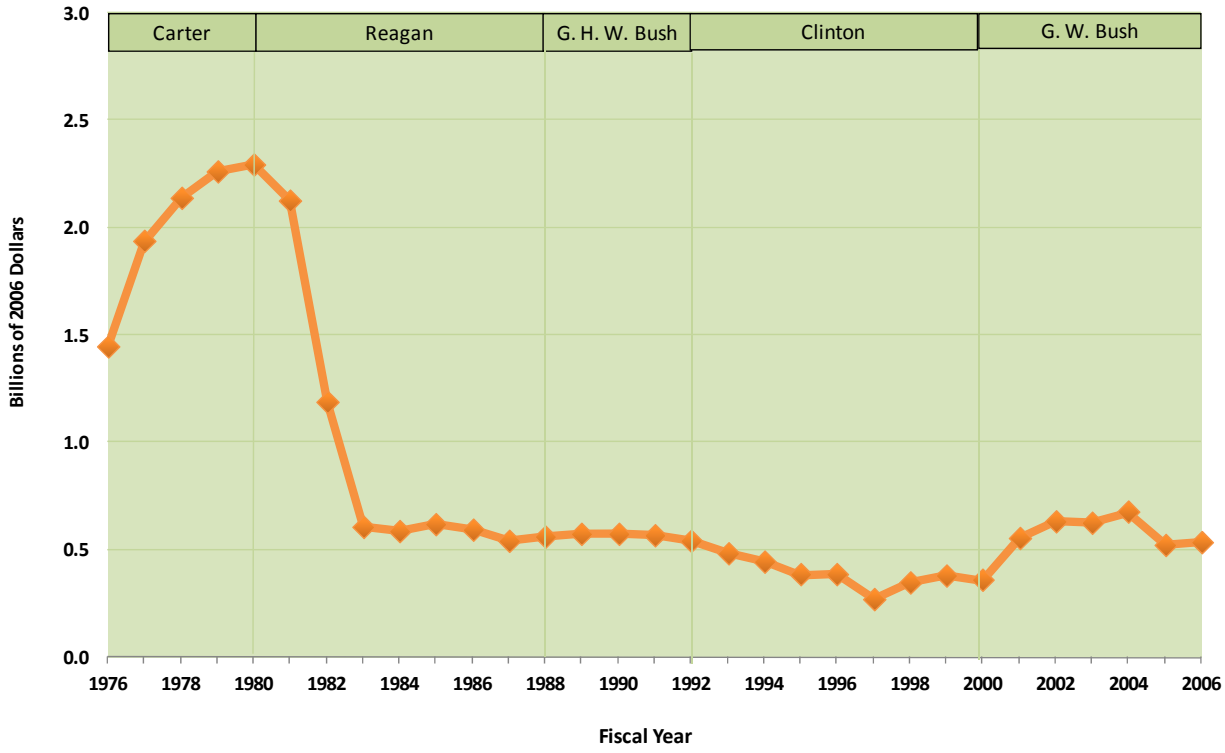
## D. Major Findings

Focusing on the period 1976–2006, the authors find that:

- The largest share of R&D funds was allocated to environment-related coal research programs at EPA, which expended $5.1 billion, 20 percent of the total. When combined with the environmental research programs within DOE, environmental research accounted for about 25 percent of the R&D budget.
- Coal liquefaction received the second largest share of the coal R&D budget—15 percent ($3.8 billion).
- R&D expenditures for surface coal gasification totaled $3 billion—11 percent of the total.
- The research program at the BOM, which consisted of a variety of coal-related research programs, expended $2.3 billion over this period—9 percent of the total.

- Research spending on combustion systems totaled $2.5 billion (10 percent of the total), and spending on magnetohydrodynamics totaled $1.5 billion (6 percent of the total).
- In constant dollars, federal funding of coal R&D bottomed out in 1997 at $274 million; by 2006 coal R&D had increased to $538 million, almost double the 1997 level (see Exhibit 27 below).

**Exhibit 27 – Federal Coal R&D Timeline, 1976–2006**



# Appendix 8 – Renewables R&D Expenditures

## A. Background

Renewable energy sources generally include solar energy (including solar heating, photovoltaics, passive systems, wind, solar thermal systems, etc.), hydroelectric power, geothermal power, alcohol fuels, and nuclear fusion. Renewables supply about 6 percent of the nation's energy, mostly in the form of hydroelectricity, geothermal energy and biomass in the wood products industry.

Of the $130.8 billion in federal energy incentives for hydroelectric power, geothermal energy and renewables, $23.7 billion were in the form of R&D expenditures, $19.1 billion of which were expended on solar and renewable energy[13]. Therefore, when discussing R&D funding in this study, renewable energy is defined narrowly to include solar energy, wind and alcohol fuels, but to exclude hydroelectric power, geothermal energy and nuclear fusion.

The history of renewable energy in the United States has been decidedly cyclical, characterized by periods of intense interest and activity and optimistic forecasts, followed by periods of slackened interest and pessimism. Between 1900 and the late 1920s, thriving solar water heating industries developed in Florida and California, only to be displaced by inexpensive natural gas and oil during the 1930s.

During the late 1940s and early 1950s, the federal government paid increased attention to renewable energy, reflecting general concerns of impending resource scarcities. This interest reached its height in the Paley Commission report issued in 1953, which questioned the future adequacy of U.S. energy resources and recommended increased R&D support for energy—including solar and renewable energy. Among other things, the Paley report predicted that by 1975, 13 million solar water heating systems would be installed throughout the United States, providing 10 percent of the nation's total energy requirements[14].

This concern over U.S. energy policy quickly evaporated during the 1950s and the next serious evidence of federal interest was the Cambel report on U.S. energy resources, technology, policy and research. This encyclopedic White House study advocated a vastly increased U.S. energy R&D effort in almost all areas, including solar and renewable technologies[15]. With the other concerns of the 1960s, however, this report also generated little interest and the nation's attention to energy problems remained unfocused for another decade.

Amid the energy concerns of the early 1970s, renewable energy was "rediscovered" during 1973–1974. Very shortly after, technologies that had been virtually ignored and programs that were practically nonexistent were being advanced as solutions to the nation's energy problems. In his April 1977 energy message, President Carter made renewables a cornerstone of the nation's energy strategy. This time, however, resources followed rhetoric, and the renewable energy budget continued to increase rapidly throughout the decade.

[13] See Table 1 in Section IV of this report.
[14] The Paley Report is given in the U.S. National Security Resources Board, "The Objectives of the United States Material Resources Policy and Suggested Steps in Their Accomplishments," Washington, D.C., 1952.
[15] See Ali Cambel, "Energy R&D and National Progress," Washington, D.C., 1966.

By the early 1980s, the combination of a new administration, the collapse of oil prices and the power of OPEC, and new national priorities de-emphasized the role of renewables, as indicated by the rapid decline in R&D funding. By the early years of the 21st century, the situation again had changed, and increased concerns about U.S. dependence on imported oil, global warming and related environmental issues increased federal officials' attention to renewable energy.

## B. The Renewable Energy Research Program

The federal government supports R&D of promising renewable energy technologies that will increase the environmentally compatible production of domestic energy resources. DOE works with industry to strengthen the technology base leading to new products and processes for the commercial market. Renewable energy R&D activities range from basic research in universities and national laboratories to applied R&D and proof-of-concept projects with industrial firms. The aim of the program is to strengthen the nation's energy security, promote energy efficiency, and increase industrial competitiveness and federal technology transfer, and it supports R&D efforts in energy efficiency and renewable technologies in utility, building, transportation and industry sectors. Renewable energy technologies currently under development will increase the contribution that renewables make to the nation's energy needs by reducing the technologies' costs and improving their performance.

Most renewable energy research is being conducted by DOE, but a small research program in photovoltaics is being carried out at NASA, and substantial research in biomass and alcohol fuels is underway in USDA. The major program components supported since 1976 include:

- solar buildings technology research
- photovoltaic energy systems
- solar thermal energy systems
- biomass and biofuels energy systems
- wind energy systems
- ocean energy systems
- hydrogen
- international solar energy program
- solar technology transfer
- program support
- resource assessment
- program direction
- electric energy systems
- energy storage systems
- renewables R&D within the conservation program
- renewable energy research at the USDA (primarily on biomass and alcohol fuels) and at NASA (primarily on photovoltaics).

## C. Renewable Energy R&D Expenditures

The authors estimate that, through 1975, the federal government's R&D expenditures for solar and renewable energy (excluding hydroelectric power and geothermal energy) totaled approximately $1.7 billion (2006 dollars). The institutional breakdown of these expenditures was as follows:

- NASA, and its predecessors, the National Advisory Council on Aeronautics and the military space programs—$650 million
- National Science Foundation—$480 million

- AEC—$140 million
- USDA—$240 million
- All other federal agencies—$240 million

These estimates were derived from federal government budget data over the period and from conversations with federal program managers and analysts who have studied the issue. The estimates are conservative, and other researchers have estimated that considerably more funds were devoted to renewable energy R&D prior to 1975. For example, Wilson Clark estimated that, in 1974 alone, the federal government spent $183 million ($641 million in 2006 dollars) on renewable energy (excluding hydroelectric power and geothermal energy).[16]

Clark's data indicate that the authors' estimates could be low by a factor of two or three. His work is notable because he is a strong advocate for solar and renewable energy and a severe critic of reliance on fossil fuels and nuclear energy. He used the estimate of federal renewable energy R&D spending of $183 million in 1974 as an example of how little the government was spending in relation to the funding priority he felt renewables should be receiving.[17] Thus, if anything, the authors' estimates may tend to be conservative; that is, they may be underestimating pre-1975 federal R&D expenditures on renewable energy.

Exhibit 28 summarizes expenditures for renewable energy research from 1976 to 2006.

### Exhibit 28 – Federal Renewables R&D, 1976–2006

**(Millions of constant 2006 dollars)**

| | 76-97 | 98-03 | 04-06 | Total |
|---|---|---|---|---|
| **U.S. DOE** | 12,851 | 2,208 | 1,246 | 16,253 |
| **U.S.D.A.** | 563 | 157 | 123 | 844 |
| **NASA** | 190 | 32 | 20 | 240 |
| **Total** | 13,604 | 2,397 | 1,389 | 17,337 |

Exhibits 29 through 31 show the program details for the renewable energy program from 1976 to 2006. As noted previously, total federal R&D expenditures on renewables through 1975 were approximately $1.7 billion. Most of this R&D was conducted by NSF, AEC, NASA and USDA. Through 2006, total federal R&D funding for renewables was about $19.1 billion, with 90 percent of the funding occurring after 1975.

The renewable energy R&D program grew very rapidly during the 1970s, from about $45 million per year in 1972 to nearly $1.7 billion annually by 1981. Program funding peaked in 1981 and then

[16] Wilson Clark, "Energy for Survival: The Alternative to Extinction," Garden City, New York: Anchor Books, 1976, p. 353.
[17] See the discussion in Ibid., pp. 352-354.

declined rapidly and substantially. Funding in 1982 ($712 million) was less than half that of the previous year, and by 1990 it reached a low point of $226 million—in real terms less than half of what it had been in 1976. Since 1990, funding for the program has more than doubled, reaching $459 million in 2006.

## Exhibit 29 – Federal R&D Expenditures for Renewable Energy, by Major Program, 1976–1997

**(Millions of constant 2006 dollars)**

| | FY76 | FY76 | FY77 | FY78 | FY79 | FY80 | FY81 | FY82 | FY83 | FY84 | FY85 | FY86 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solar Energy** | 356 | 108 | 678 | 816 | 1,282 | 1,334 | 1,340 | 526 | 378 | 325 | 312 | 245 |
| **Solar Buildings Technology Research** | 111 | 33 | 79 | 81 | 225 | 197 | 143 | 45 | 23 | 29 | 17 | 13 |
| **Photovoltaic Energy Systems** | 68 | 22 | 170 | 205 | 299 | 336 | 292 | 145 | 108 | 89 | 100 | 69 |
| **Solar Thermal Energy Systems** | 86 | 22 | 260 | 262 | 291 | 326 | 247 | 104 | 93 | 79 | 60 | 44 |
| **Biofuels Energy Systems** | 15 | 7 | 29 | 57 | 105 | 128 | 132 | 60 | 38 | 51 | 53 | 46 |
| **Wind Energy Systems** | 44 | 15 | 60 | 94 | 149 | 144 | 167 | 67 | 58 | 48 | 51 | 43 |
| **Ocean Energy Systems** | 19 | 7 | 40 | 94 | 103 | 105 | 81 | 37 | 21 | 11 | 8 | 9 |
| **International Solar Energy Program** | -- | -- | -- | -- | -- | -- | 32 | 8 | 19 | 1 | 1 | 4 |
| **Solar Technology Transfer** | 7 | 3 | 40 | 24 | 35 | 55 | 86 | 20 | 7 | 4 | 11 | 4 |
| **National Renewable Energy Lab.** | -- | -- | -- | -- | -- | 15 | 21 | -- | -- | -- | -- | 3 |
| **Program Support** | -- | -- | -- | -- | -- | 10 | 14 | -- | 2 | 1 | 1 | 1 |
| **Resource Assessment** | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1 |
| **Program Direction – Other Solar Energy** | 7 | -- | -- | -- | 75 | 19 | 127 | 41 | 11 | 11 | 9 | 9 |
| **Electric Energy Systems** | 27 | 12 | 40 | 79 | 80 | 85 | 83 | 41 | 32 | 34 | 36 | 21 |
| **Energy Storage Systems** | 49 | 19 | 93 | 159 | 161 | 152 | 152 | 74 | 48 | 47 | 33 | 29 |
| **Solar/Renewables R&D in Conservation** | 10 | 3 | 21 | 24 | 35 | 41 | 48 | 20 | 19 | 20 | 21 | 21 |
| **DOE Solar/ Renewables Tech. Base** | 442 | 142 | 832 | 1,078 | 1,558 | 1,612 | 1,623 | 661 | 477 | 425 | 401 | 316 |
| **USDA Solar/ Renewables R&D** | 15 | 7 | 26 | 31 | 31 | 32 | 40 | 41 | 43 | 36 | 33 | 24 |
| **NASA Solar/ Renewables R&D** | 15 | 3 | 14 | 13 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 |
| **Total Federal Solar/Renewables R&D** | 472 | 152 | 873 | 1,121 | 1,600 | 1,655 | 1,674 | 712 | 529 | 470 | 443 | 349 |

## Continued
## Exhibit 29 – Federal R&D Expenditures for Renewable Energy, by Major Program, 1976–1997

**(Millions of constant 2006 dollars)**

| | FY87 | FY88 | FY89 | FY90 | FY91 | FY92 | FY93 | FY94 | FY95 | FY96 | FY97 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solar Energy** | 205 | 153 | 140 | 131 | 178 | 239 | 249 | 326 | 326 | 249 | 227 | 10,122 |
| **Solar Buildings Technology Research** | 10 | 9 | 8 | 1 | 2 | 2 | 3 | 7 | 4 | 2 | 2 | 1,046 |
| **Photovoltaic Energy Systems** | 67 | 56 | 56 | 52 | 65 | 81 | 87 | 103 | 107 | 75 | 71 | 2,722 |
| **Solar Thermal Energy Systems** | 37 | 26 | 23 | 22 | 26 | 40 | 36 | 44 | 37 | 29 | 26 | 2,219 |
| **Biofuels Energy Systems** | 40 | 26 | 20 | 23 | 46 | 53 | 64 | 76 | 65 | 65 | 65 | 1,266 |
| **Wind Energy Systems** | 27 | 14 | 13 | 13 | 15 | 29 | 32 | 38 | 57 | 38 | 35 | 1,251 |
| **Ocean Energy Systems** | 9 | 7 | 7 | 7 | 3 | 2 | 1 | 1 | 0 | 0 | 0 | 568 |
| **International Solar Energy Program** | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 7 | 11 | 4 | 1 | 97 |
| **Solar Technology Transfer** | 4 | 4 | 3 | 2 | 2 | 1 | 2 | 26 | 17 | 13 | 0 | 372 |
| **National Renew-able Energy Laboratory** | 1 | 1 | 1 | 1 | 8 | 17 | 10 | 8 | 8 | 1 | 3 | 98 |
| **Program Support** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 | 0 | 0 | 0 | 44 |
| **Resource Assessment** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 4 | 2 | 0 | 17 |
| **Program Direc-tion –Other Solar Energy** | 7 | 7 | 7 | 7 | 7 | 8 | 9 | 9 | 15 | 17 | 23 | 421 |
| **Electric Energy Systems** | 19 | 24 | 36 | 26 | 38 | 43 | 43 | 64 | 46 | 40 | 33 | 981 |
| **Energy Storage Systems** | 27 | 24 | 20 | 17 | 19 | 10 | 13 | 8 | 7 | 2 | 4 | 1,166 |
| **Solar/Renewables R&D in Conservation** | 20 | 17 | 17 | 23 | 24 | 29 | 34 | 37 | 38 | 32 | 29 | 582 |
| **DOE Solar/ Renewables Energy Tech.** | 270 | 218 | 213 | 197 | 259 | 321 | 338 | 435 | 417 | 323 | 293 | 12,851 |
| **Dept. of Agriculture Solar/ Renewables R&D** | 22 | 21 | 22 | 21 | 20 | 22 | 15 | 17 | 17 | 14 | 14 | 563 |
| **NASA Solar/ Renewables R&D** | 9 | 9 | 8 | 8 | 8 | 8 | 3 | 3 | 3 | 3 | 3 | 190 |
| **Total Federal Solar/Renewables R&D** | 301 | 248 | 242 | 226 | 286 | 350 | 357 | 456 | 437 | 340 | 311 | 13,603 |

### Exhibit 30 – Federal Renewable Energy R&D, 1998–2003

**(Millions of constant 2006 dollars)**

| | FY98 | FY99 | FY00 | FY01 | FY02 | FY03 | Total 98–03 |
|---|---|---|---|---|---|---|---|
| **Solar Energy** | | | | | | | |
| **Solar Buildings Technology Research** | 3.3 | 4.4 | 2.2 | 4.4 | 3.3 | 4.4 | 22.0 |
| **Photovoltaic Energy Systems** | 77.4 | 84.0 | 75.3 | 85.1 | 78.5 | 79.6 | 479.9 |
| **Solar Thermal Energy Systems** | 20.1 | 19.6 | 17.5 | 16.4 | 14.2 | 5.5 | 93.3 |
| **Zero Energy Buildings** | -- | -- | -- | -- | 1.1 | 8.7 | 9.8 |
| **Biopower/Biofuels Energy Systems** | 70.9 | 85.1 | 79.6 | 97.1 | 98.2 | 93.8 | 524.7 |
| **Wind Energy Systems** | 39.3 | 40.4 | 37.1 | 45.8 | 42.5 | 45.8 | 250.9 |
| **International Renewable Energy Program** | 1.1 | 7.6 | 5.5 | 5.5 | 3.3 | 3.3 | 26.3 |
| **National Renewable Energy Laboratory** | 1.1 | 4.4 | 1.1 | 4.4 | 0.0 | 0.0 | 11.0 |
| **Program Support** | -- | -- | 5.5 | 4.4 | 1.1 | 1.1 | 12.1 |
| **Program Direction** | 13.1 | 16.4 | 16.4 | 17.5 | 17.5 | 9.8 | 90.7 |
| **Hydrogen R&D** | 19.6 | 26.2 | 27.3 | 30.5 | 32.7 | 41.4 | 177.7 |
| **Electric Energy Systems and Storage** | 51.3 | 48.0 | 42.5 | 58.9 | 76.4 | 78.5 | 355.6 |
| **Renewables R&D in DOE Conservation** | 10.9 | 12.0 | 32.7 | 27.3 | 40.4 | 30.5 | 153.8 |
| **USDA Renewables R&D** | 10.9 | 10.9 | 15.3 | 19.6 | 33.8 | 66.5 | 157.0 |
| **NASA Solar** | 4.4 | 4.4 | 5.5 | 5.5 | 5.5 | 6.5 | 31.8 |
| **Total Federal Solar/Renewables R&D** | 323.4 | 363.4 | 363.5 | 422.4 | 448.5 | 475.4 | 2396.6 |

### Exhibit 31 – Federal Renewable Energy R&D, 2004–2006

**(Millions of constant 2006 dollars)**

| | FY04 | FY05 | FY06 | Total 04-06 |
|---|---|---|---|---|
| **Solar Energy** | | | | |
| **Solar Buildings Technology Research** | 8 | 6 | 7 | 21 |
| **Photovoltaic Energy Systems** | 77 | 78 | 75 | 230 |
| **Solar Thermal Energy Systems** | 3 | 3 | 3 | 9 |
| **Biopower/Biofuels Energy Systems** | 98 | 91 | 73 | 262 |
| **Wind Energy Systems** | 42 | 42 | 44 | 128 |
| **International Renewable Energy Program** | 6 | 6 | 3 | 15 |
| **Program Support** | 7 | 6 | 2 | 15 |
| **Program Direction** | 18 | 20 | 19 | 57 |
| **Hydrogen** | 85 | 97 | 99 | 281 |
| **Fuel Cells** | 67 | 77 | 84 | 228 |
| **USDA Renewables R&D** | 43 | 37 | 43 | 123 |
| **NASA Solar R&D** | 6 | 7 | 7 | 20 |
| **Total Federal Solar/Renewables R&D** | 460 | 470 | 459 | 1,389 |

## D. Major Findings

The authors find:

- The photovoltaics program received the largest share of renewable energy R&D funds between 1976 and 2006—$3.4 billion (20 percent of the total).
- Since 1950, photovoltaics have received 23 percent of all renewable energy R&D expenditures—approximately $3.9 billion.

- The program receiving the second largest share of research support between 1976 and 2006 was the biomass/biofuels program in DOE and USDA—$2.9 billion (17 percent of the total).
- The third largest share of R&D funds expended since 1976 was spent on the solar thermal systems program, which received $2.4 billion (14 percent of the total).
- Between 1976 and 2006, wind energy R&D programs received $1.6 billion—about 9 percent of total renewables R&D funding over this period. The trend in federal spending on renewables R&D is shown in Exhibit 32.
- Over the past decade, the funding priorities for solar buildings technology and ocean energy systems have been greatly reduced, while the research priorities for biofuel/biomass energy systems and hydrogen R&D have increased.

**Exhibit 32– Federal Renewables R&D Timeline, 1976–2006**