Two Thirds of a Century and $1 Trillion+ U.S. Energy Incentives

Analysis of Federal Expenditures for Energy Development, 1950-2016

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By

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Executive Summary

For decades the federal government has employed a variety of incentives to support research, development, and deployment of energy technologies. 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 compilation of the amounts and types of incentives provided from 1950 to 2016 and the energy sources targeted with each type of incentive. As summarized in Exhibit 1 below, the findings indicate that oil, gas, hydro, and solar, wind, and biomass received more than 90 percent 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. For the last 20 years, federal spending on R&D for coal and for renewables has exceeded spending on nuclear energy R&D. Over the past six years, 2011 through 2016, renewable energy received more than three times as much help in federal incentives as oil, natural gas, coal, and nuclear combined, and 27 times as much as nuclear energy.

Exhibit 1 – Summary of Federal Energy Incentives, 1950–2016

(Billions of 2015 Dollars[1])

TYPE OF INCENTIVE	ENERGY SOURCE							SUMMARY	
	Oil	Natural Gas	Coal	Hydro	Nuclear	Renewables[2]	Geothermal	Total	Share
Tax Policy	218	122	40	14	-	84	2	**479**	47%
Regulation	138	5	11	6	18	1	-	**179**	18%
R&D	9	8	43	2	85	32	6	**185**	18%
Market Activity	8	3	3	78	-	4	2	**98**	10%
Gov't Services	38	2	19	2	2	3	-	**66**	6%
Disbursements	3	-	-4	3	–27	34	1	**10**	1%
Total	**414**	**140**	**112**	**105**	**78**	**158**	**11**	**1,018**	
Share	40%	14%	11%	10%	8%	16%	1%		100%

[1] All estimates quoted are in 2015 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, solar, and biomass.

About Management Information Services, Inc.

Management Information Services, Inc. is an economic and energy research firm with expertise on a wide range of complex issues, including energy, electricity, and the environment. The MISI staff offers specializations in economics, information technology, engineering, and finance, and includes former senior officials from private industry, the federal government, and academia.

Over the past three decades MISI has conducted extensive research, and since 1985 has assisted hundreds of clients, including Fortune 500 companies, nonprofit organizations and foundations, the UN, 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 U.S. Energy Information Administration, the U.S. Department of Defense, the U.S. Marine Corps, the U.S. Air Force, NASA, NHTSA, the National Energy Technology Laboratory, the U.S. General Services Administration, and the National Academies of Science. 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 *www.misi-net.com*.

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I. Introduction

With increasing concern about energy prices, availability, reliability, and environmental impact, public interest has risen sharply in the role of federal incentives in shaping the energy marketplace and future energy options. But the public has been frustrated, and often given half-truths, because of the difficulty in developing a complete picture of the incentives. 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 nearly 70 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 federal incentives. MISI's long history of research and publications in energy and economics for the National Academy of Sciences, the U.S. Department of Energy, the UN, and others assured that MISI would provide the expertise and objectivity necessary to collect and analyze the data required for this independent assessment.

The study provides a compilation of the amounts spent from 1950 to 2016, 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 renewables, receiving more than half (56 percent) 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 two decades, federal spending on R&D for coal and for renewables has exceeded expenditures for nuclear energy R&D. Over the past six years, 2011 through 2016, renewable energy (solar, wind, and biomass) received more than three times as much federal help as oil, natural gas, coal, and nuclear combined, and 27 times as much as nuclear energy.

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 amounts expended on incentives for the seven energy sources examined. Section V focuses on expenditures for a high-profile incentive, R&D. Section VI offers conclusions.

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 Treasury Department, the Office of Management and Budget (OMB), the Congressional Budget Office (CBO), 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 using 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 2015 dollars using price deflators derived from data published by OMB, CBO, 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., under the federal tax code. Tax policy has been, by far, the most widely used incentive mechanism, accounting for $479 billion (47 percent) of all federal energy incentives since 1950. The oil and gas industries, for example, receive depletion allowances and intangible drilling cost provisions as an incentive for exploration and development. Federal tax credits and deductions also have been us0ed to encourage the use of renewable energy, which has been the second largest beneficiary of tax incentives.

B. Regulation

This category encompasses federal mandates and government-funded oversight of, or controls on, businesses deploying 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 $179 billion (18 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 exempted from federal requirements that raise costs or limit prices, and 2) costs of federal regulation that are borne by the general tax revenues 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 (when they existed) on 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 that pipelines can collect from consumers. .

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 2016 was approximately $18 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 $1, 018 billion in total federal spending on energy since 1950, research and development funding comprised about 18 percent ($189 billion).

D. Market Activity

This incentive includes direct federal government involvement in the marketplace. Through 2016, federal market activity totaled $98 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 $66 billion through 2016, representing six percent of total incentives. Relevant recipients 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 $10 billion, less than one percent 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 2016, the Nuclear Waste Trust Fund had accumulated a $27 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. Another example of Federal disbursements is §1603 of the American Recovery and Reinvestment Tax Act program, which offered renewable energy project developers cash payments in lieu of investment tax credits.

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 $1,018 billion for energy developments since 1950.
- The largest type of incentive has been tax concessions, amounting to about 47 percent of all incentives.
- Federally funded regulation and R&D, at about 18 percent each, are the second and third largest incentives.

Exhibit 2 – Summary of Federal Energy Incentives, 1950–2016

(Billions of 2015 Dollars[3])

TYPE OF INCENTIVE	ENERGY SOURCE							SUMMARY	
	Oil	Natural Gas	Coal	Hydro	Nuclear	Renewables[4]	Geothermal	Total	Share
Tax Policy	218	122	40	14	-	84	2	**479**	47%
Regulation	138	5	11	6	18	1	-	**179**	18%
R&D	9	8	43	2	85	32	6	**185**	18%
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Share	40%	14%	11%	10%	8%	16%	1%		100%

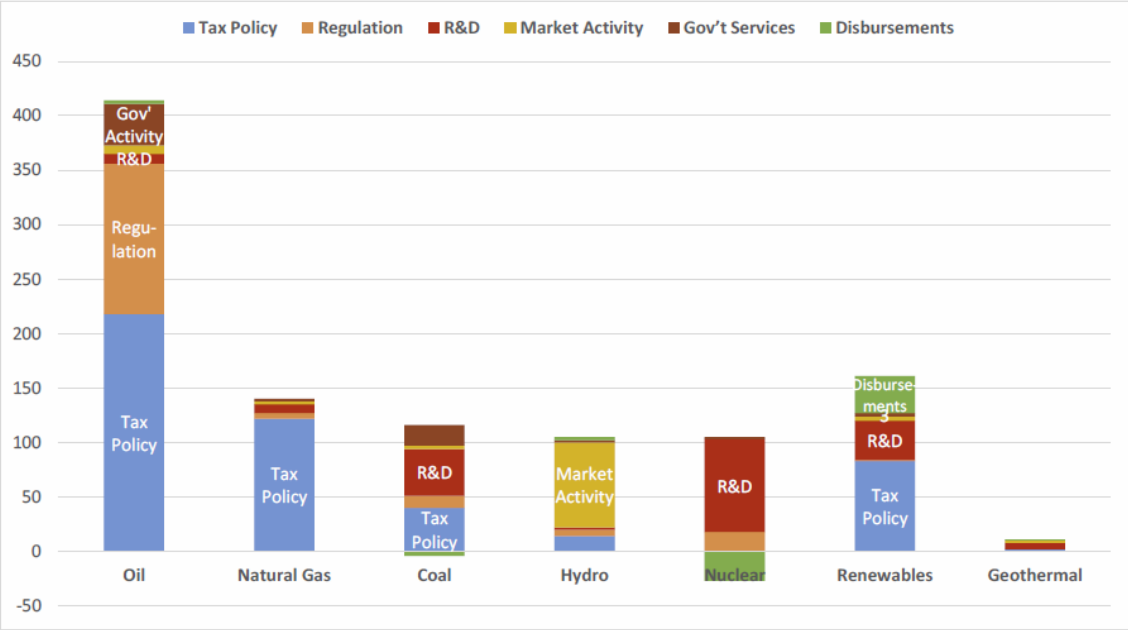
The dominance of oil incentives is apparent in Exhibit 3. This exhibit also shows that renewables have been the second largest beneficiaries of federal incentives and that natural gas has been the third largest beneficiary. Using a broader definition of renewable energy to also include hydro and geothermal indicates that, under this definition, renewable energy received 27% of all federal energy incentives.

[3] All estimates quoted are in constant 2015 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.

[4] Renewables are primarily wind, solar, and biomass.

Exhibit 3 – Comparison of Federal Expenditures for Energy Development, 1950–2016

(Billions of 2015 Dollars)



Federal tax concessions for oil and gas are the largest of all incentives, amounting to over 70 percent of all tax-related allowances for energy. Regulation of prices on oil for stripper wells or new wells, and related incentives, comprises the second largest amount of incentives aimed at a particular energy type.

In the R&D category, nuclear energy received about 45 percent of the expenditures since 1950, coal about 23 percent, and renewables about 17 percent of the total.

Some additional observations on the data:

- Oil and gas received 54 percent ($554 billion) of federal spending to support energy since 1950. Oil alone received three-fourths ($414 billion) of this amount.
- Wind, solar and geothermal received approximately 17 percent ($169 billion).
- Coal received approximately 11 percent ($112 billion) of federal spending.
- Hydro received approximately 10 percent ($105 billion) of federal spending.
- Nuclear received approximately eight percent ($78 billion) of federal spending.
- Nuclear energy was the beneficiary of about 45% ($85 billion) of the government's spending on energy R&D.
- About $46 billion (almost 55 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 2016, the mix for each energy type is shown in Exhibits 4 and 5.

Exhibit 4 – Mix of Federal Expenditures for Each Energy Source

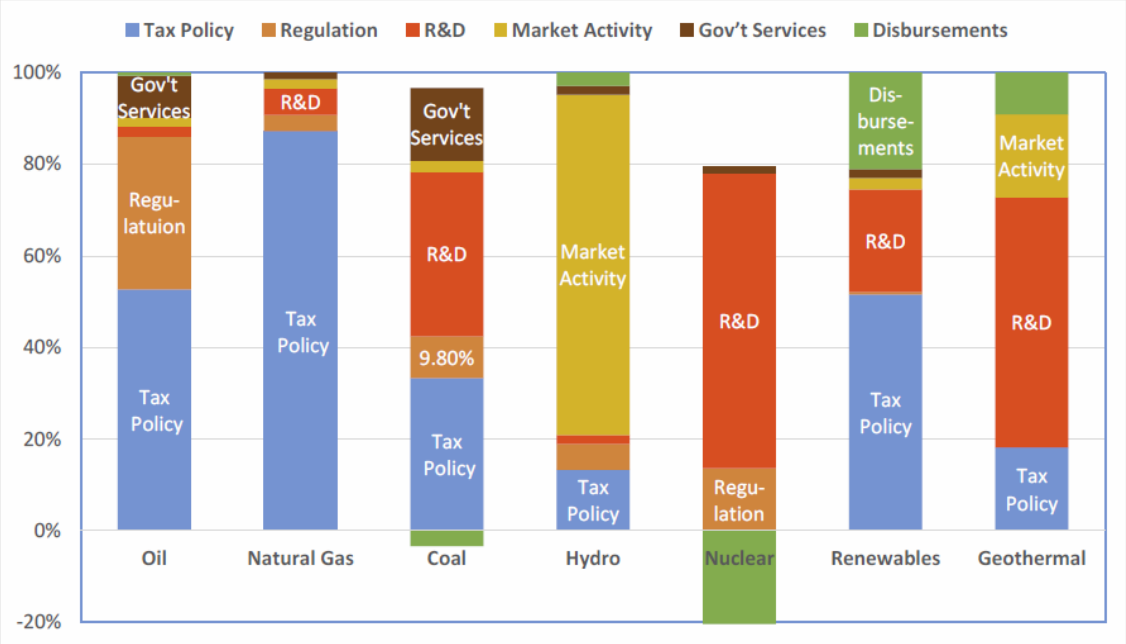


Exhibit 5 – Mix of Federal Expenditures for Each Energy Source
(Percent)

TYPE OF INCENTIVE	ENERGY SOURCE						
	Oil	Natural Gas	Coal	Hydro	Nuclear	Renewables	Geothermal
Tax Policy	52.7%	87.1%	35.7%	13.3%	0.0%	53.2%	18.2%
Regulation	33.3%	3.6%	9.8%	5.7%	23.1%	0.6%	0.0%
R&D	2.2%	5.7%	38.4%	1.9%	109.0%	20.3%	54.5%
Market Activity	1.9%	2.1%	2.7%	74.3%	0.0%	2.5%	18.2%
Gov't Services	9.2%	1.4%	17.0%	1.9%	2.6%	1.9%	0.0%
Disbursements	0.7%	0.0%	-3.6%	2.9%	-34.6%	21.5%	9.1%

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 the commercialization of nuclear-generated electricity.

In the mid-1970s, federal support for all energy R&D grew sharply after the oil price shocks and "energy crisis," 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 in place 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 2016. 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 Eengy Commission, and its successors, the U.S. Energy Research and Development Administration (ERDA) and DOE, between 1950 and 2016. 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.

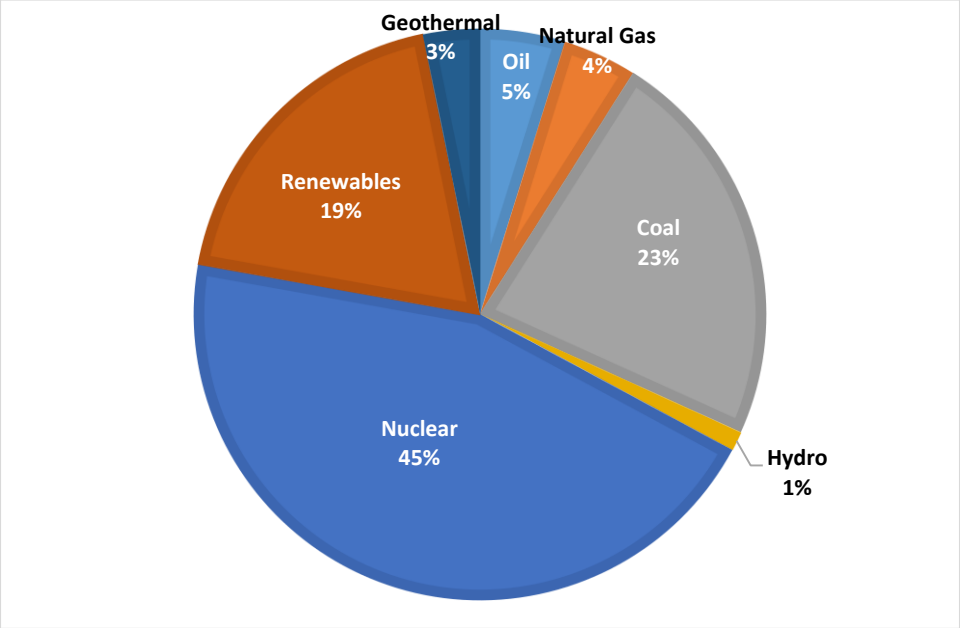
The renewable energy program is defined to include renewable energy in all of its manifestations, e.g., photovoltaics, solar thermal systems, biomass, and wind. It excludes all other renewable energy sources, specifically hydroelectric power and geothermal power, which are tabulated individually, and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

[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.

1950 and 2016 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 6.

Exhibit 6 – Allocation of Federal R&D Expenditures, 1950–2016



Analysis of federal budget data since 1950 shows:

- Nearly 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 $3.4 billion in 1978 and declined to a low of $85 million in 2001.
- Since 1976, only about 10 percent of the total of $85 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 2016, 44 percent ($17 billion) was devoted to the breeder program. Since 1950, the breeder program consumed 33 percent—$28

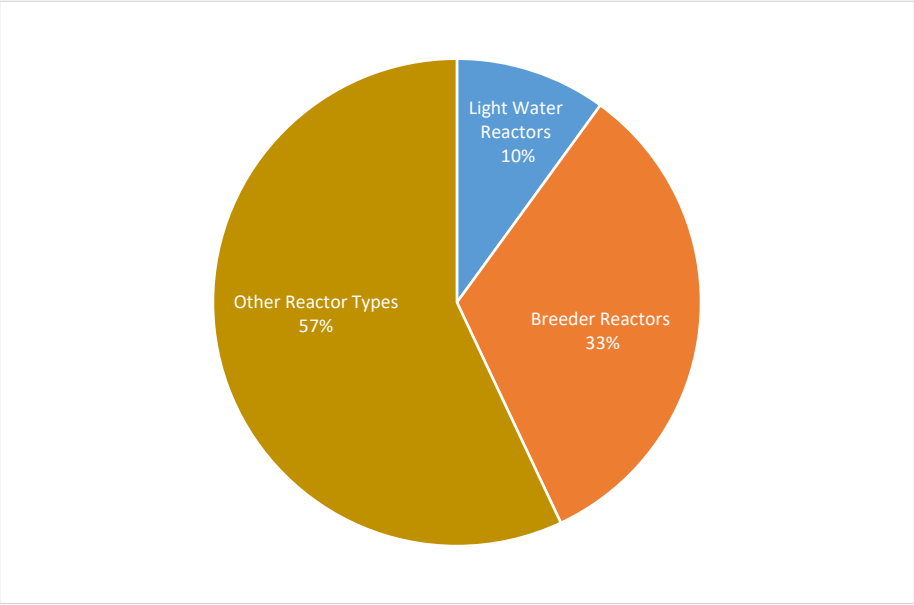
[6]Of the energy sources commonly considered "renewables," hydro comprised one percent of R&D funding and is tracked separately in this report; and geothermal R&D funding, also tracked separately, comprised three percent of total R&D funding.

billion of $85 billion—of civilian nuclear energy R&D. Funding for research on the breeder reactor ended in 1988.

- The light water reactor program always has been a small portion of nuclear energy research, accounting for $8.6 billion (10 percent) of the $85 billion total R&D expenditures. Light water reactors produce about 20 percent of the nation's electricity.
- More than $48 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 7.

Exhibit 7 – Allocation of Nuclear R&D Funding, 1950–2016



- Annual R&D expenditures for nuclear, coal and renewables peaked between 1979 and 1981 and then declined dramatically. This decline continued through the late 1990s, as shown in Exhibit 8. In the last 10 years (2007 to 2016), the cumulative expenditure for nuclear R&D was less than that for coal and only about half of that for renewables (wind, solar, and biomass), as shown in Exhibit 9.
- Annual R&D expenditures for nuclear have been less than those for renewables every year since 1994.

Exhibit 8 – Annual Federal R&D Expenditures, 1976–2016

(Millions of 2015 Dollars)

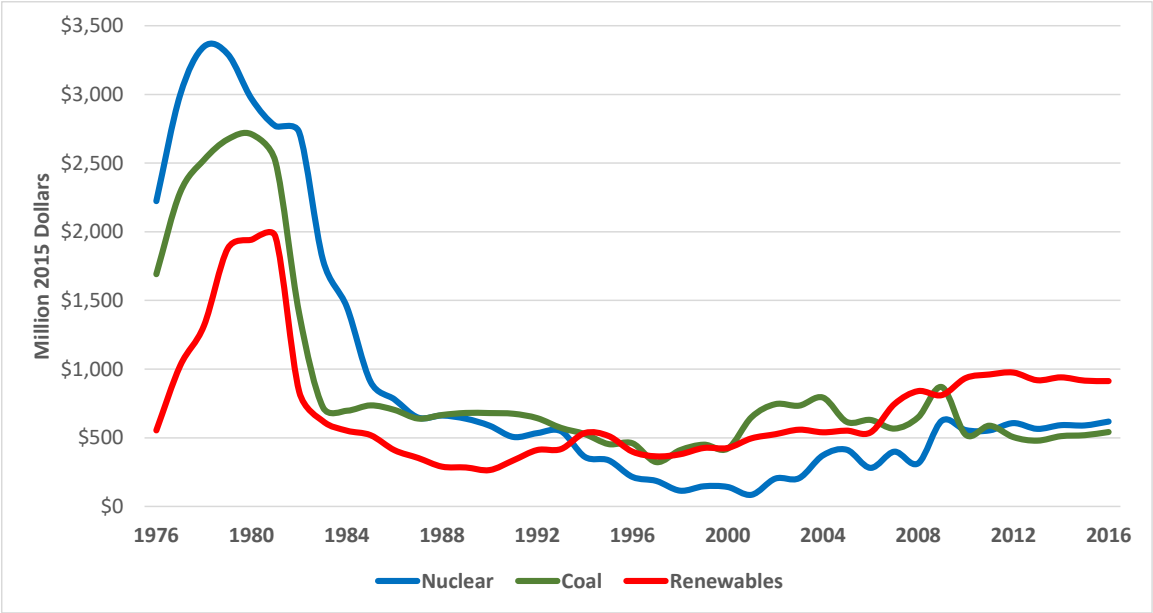
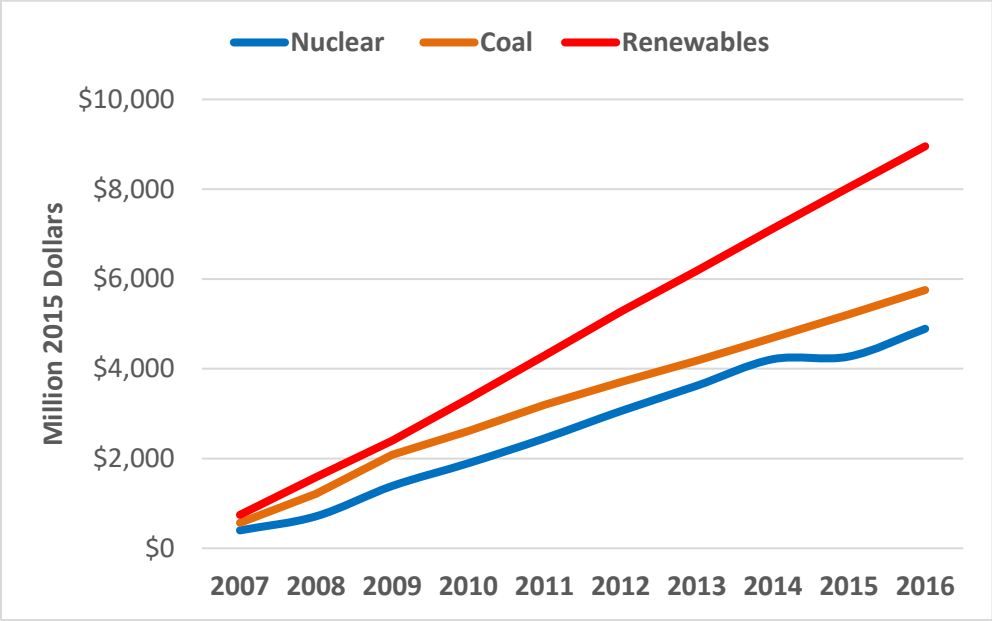


Exhibit 9 – Cumulative Federal R&D Expenditures, 2000–2016

(Millions of 2015 Dollars)



VI. Conclusions

The data contradict the common perception that federal energy incentives have favored nuclear energy at the expense of renewables, such as wind and solar. The largest beneficiaries of federal energy incentives have been oil and renewables, receiving well over 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 also been less than spending on renewable energy research. Since 2007, federal spending on renewables research has been nearly twice as large as federal research spending on either coal or nuclear. Over the past six years, 2011 through 2016, renewable energy received more than three times as much federal incentives as oil, natural gas, coal, and nuclear combined, and 27 times as much federal incentives as did nuclear energy.

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 October 1977 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

AEA	Atomic Energy Act of 1946
AEC	U.S. Atomic Energy Commission
AES	Advanced Energy Systems
ARRA	American Recovery and Reinvestment Act of 2009
ATW	Accelerator Transmutation of Nuclear Waste
BEA	Bureau of Economic Analysis, U.S. Department of Commerce
BLM	Bureau of Land Management, U.S. Department of the Interior
BLS	Bureau of Labor Statistics, U.S. Department of Labor
BOM	Bureau of Mines, U.S. Department of the Interior
CBO	Congressional Budget Office
CCC	Commodity Credit Corporation
CCT	Clean Coal Technology
CCS	Carbon Capture and Storage
CRDP	AEC Civilian Reactor Development Program
CPI	Consumer Price Index
CCPI	Clean Coal Power Initiative
DOE	U.S. Department of Energy
DOC	U.S. Department of Commerce
DOI	U.S. Department of the Interior
EDX	Energy Data Exchange
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
EPAct	Energy Policy Act of 2005
FEA	U.S. Federal Energy Administration
FEO	U.S. Federal Energy Office
FERC	U.S. Federal Energy Regulatory Commission
FFTR	Fast Flux Test Reactor
GDP	Gross Domestic Product
IGCC	Integrated Gasification Combined Cycle

IPD	Implicit Price Deflator
ITC	Investment Tax Credit
LWR	Light Water Reactor
NACA	National Advisory Council on Aeronautics
NARUC	National Association of Regulatory Utility Commissioners
NAS	National Academes of Science
NASA	National Aeronautics and Space Administration
NETL	National Energy Technology laboratory
NRAP	National Risk Assessment Partnership
NRC	Nuclear Regulatory Commission
NSF	National Science Foundation
OMB	Office of Management and Budget
OTA	Office of Technology Assessment, U.S. Congress
OPEC	Organization of the Petroleum Exporting Countries
R&D	Research and Development
RCSPs	Regional Carbon Sequestration Partnerships
R,D,&D	Research, Development, and Deployment
RE	Renewable Energy
SCO_2	Supercritical Carbon Dioxide Technology
SMR	Small Modular Reactor
STEP	Supercritical Transformational Electric Power Generation
TQ	Transition Quarter
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
1950–2016	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.
1975–2016[7]	The annual budgets and supporting documents of DOI, USDA, NASA and EPA.
1978–2016	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).
1975–1977	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 GDP estimates for 2016 were those contained in the *Budget of the United States Government, Fiscal Year 2016*. The R&D expenditure estimates used were the actual dollars as expended in the year in question. These were subsequently converted to constant 2015 dollars.

In addition, valuable 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 2016. 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
	Capital Gains Treatment of Royalties on Coal	Tax Policy	1987
	Alternative Fuels Production Tax Credit	Tax Policy	1987
	Credit for Investment in Clean Coal Facilities	Tax Policy	2005
	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
	Expensing of Exploration and Development Costs	Tax Policy	1954
	Percentage Depletion Allowance	Tax Policy	1950
	Maintenance of Ports and Waterways	Regulation	1950
	Stripper Well Price Incentives	Regulation	1944–45; 1974–81

Exhibit 11 – Alignment of Federal Programs to Incentive Types, cont.			
Oil – cont.	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
	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 Power 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, Wind, and Biomass)	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
	Renewable Electricity Production Tax Credit	Tax Policy	1992
	Credit for Holding Clean Renewable Energy Bonds	Tax Policy	2005
	Bio-diesel and small agri-biodiesel producer tax credit	Tax Policy	2004
	Alcohol Fuel Credit	Tax Policy	1984
	USDA Biomass Crop Assistance Program	Disbursements	2008
	USDA Bioenergy Program for Advanced Biofuels	Disbursements	1999
	Renewable Transportation Fuels and Volumetric Ethanol Excise Tax Credit	Tax Policy	2006
	Credit for Purchase of Residential Solar and Fuel Cells	Tax Policy	2006
	Section 1603 Treasury Grant for Renewable Energy (in lieu of ITC)	Disbursements	2009
	Federal Loan Guarantee Programs	Market Activity	2009
	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 2016, federal incentives for nuclear netted to approximately $78 billion—eight 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 up to $6 billion in production tax credits for electricity from new nuclear plants. No money has been paid under the program so far.

b. Regulation. Approximately $18 billion through 2016; 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 $85 billion through 2016.

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 2016 the total for all other federal incentives and support activities was about $2 billion.

f. Disbursements. There initially were federal disbursements for nuclear energy for waste management and disposal; these funds are included under R&D monies. Under the Nuclear Waste Policy Act of 1982, however, nuclear utilities are assessed the costs of developing a high-level waste repository for spent fuel from nuclear plants.

Since 2010, the Obama Administration has taken a variety of actions to terminate development of a geologic repository for nuclear waste at Yucca Mountain in Nevada -- the only site where such waste is authorized to be stored under current law. Although Federal agencies have continued activities related to licensing that facility, the Congress has since provided no new funding to DOE to build it.

Largely in response to such actions, the National Association of Regulatory Utility Commissioners (NARUC) and the Nuclear Energy Institute filed petitions with the U.S. Court of Appeals for

[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.

the District of Columbia Circuit to end the federal government's collection of fees paid by nuclear power generators to cover the cost of disposing of civilian nuclear waste. In November 2013, that court effectively ordered DOE to suspend collection of annual fees from nuclear power generators. The court found that in DOE's most recent assessment of the adequacy of the fees to cover the lifetime costs of disposal, the department had failed to provide a legally justifiable basis for continuing to collect fees in the absence of an identifiable strategy for waste management. In May 2014, pursuant to the court's order, DOE stopped collecting disposal fees, which had previously totaled roughly $750 million per year. Through 2016 this fund had accumulated $34.3 billion more than had been disbursed. Through 2016 the federal government has expended approximately $7.6 billion for environmental restoration related to commercial nuclear energy. Thus, federal disbursements for nuclear energy net to –$26.7 billion.

2. **Coal.** Through 2016, federal incentives for coal totaled $112 billion—11 percent of the federal incentives for energy development.

    a. Tax Policy. Through 2016, 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, and related incentives resulted in a tax subsidy of $40 billion.

    b. Regulation. Federal expenditures for regulating mine health and safety and other aspects of the coal industry totaled $11 billion through 2016.

    c. R&D. Through 2016, the coal industry received $43.2 billion in R&D funding. Most of these expenditures were DOE coal R&D monies. Significant expenditures, however, 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 $3.1 billion through 2016, 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 $18.6 billion through 2016.

    f. Disbursements. As of 2016, the Black Lung Disability Trust Fund had a positive balance of $1.6 billion, and the Abandoned Mine Reclamation Fund had a positive balance of $2.5 billion, resulting in net federal disbursements for the coal industry of approximately -$4.1 billion.

3. **Oil.** Through 2016, federal incentives for oil totaled $414 billion—40 percent of the federal incentives for energy development.

    a. Tax Policy. The authors estimate that, through 2016, tax incentives for the oil industry totaled $218 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 $138 billion through 2016. 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 2016, federal R&D incentives for the oil industry totaled $9 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 approximately $8 billion through 2016.

e. Government Services. Government services incentives ($38 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 2016.

f. Disbursements. Through 2016, the federal government disbursed approximately $7.5 billion to the oil industry, primarily through subsidies for construction and operating costs of oil tankers. As of 2016, however, the combined balances in the Leaking Underground Storage Tank Trust Fund and the Oil Spill Liability Fund totaled $4.9 billion. Thus, the net federal disbursements for the oil industry totaled $2.6 billion through 2016.

4. Natural Gas. Through 2016, federal incentives for natural gas totaled $140 billion—14 percent of the federal incentives for energy development.

a. Tax Policy. The authors estimate that through 2016, tax incentives for the natural gas industry totaled $122 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 approximately $5 billion through 2016. 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 2016, federal R&D funds for the natural gas industry totaled $7.7 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 $2.7 billion through 2016.

e. Government Services. Traditional services incentives ($1.9 billion) resulted primarily from miscellaneous services provided by the federal government to the industry through 2016.

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

5. **Hydroelectric.** Through 2016, federal incentives for hydroelectric energy totaled $105 billion—10 percent of the federal incentives for energy development.

    a. Tax Policy. The authors estimate that, through 2016, the exemption of power revenues from federal taxes resulted in a tax expenditure subsidy for the development of hydro-electric energy of $14 billion.

    b. Regulation. Expenditures for the regulation of hydroelectric energy through FERC and other regulatory agencies totaled approximately $6 billion through 2016.

    c. R&D. Through 2016, federal R&D expenditures for hydroelectric energy in DOE, its predecessors, and the U.S. Army Corps of Engineers totaled approximately $1.7 billion.

    d. Government Services. Traditional services through the support of numerous federal agencies resulted in a subsidy for hydroelectric energy of approximately $2 billion through 2016.

    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 approximately $78 billion through 2016.

    f. Disbursements. Through 2016 the federal government disbursed approximately $3 billion for hydroelectric energy development.

6. **Renewables.** Through 2016, federal incentives for renewables (solar, wind and biomass) totaled $158 billion—16 percent of federal incentives for energy development.

    a. Tax Policy. The authors estimate that, through 2016, tax incentives for renewable energy totaled $84 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 renewable electricity production tax credit, the alcohol fuel credit, and the partial exemption from the excise tax for alcohol fuels.

    b. Regulation. Federal regulation costs for renewable energy totaled approximately $1 billion through 2016.

    c. R&D. Through 2016, federal R&D incentives for renewable energy totaled $32 billion. These resulted primarily from federal R&D expenditures by ERDA and DOE.

    d. Government Services. Government services incentives of $2.8 billion through 2016 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 approximately $4 billion through 2016.

    f. Disbursements. Federal disbursements are made to encourage renewable energy

use through various federal programs, including under §1603 of the American Recovery and Reinvestment Tax Act (ARRA) program which offered renewable energy project developers cash payments in lieu of investment tax credits, and totaled approximately $34 billion through 2016.

7. **Geothermal Energy**. Through 2016, federal incentives for geothermal energy totaled $11 billion—one percent of the federal incentives for energy development.

a. Tax Policy. The authors estimate that, through 2016, targeted tax expenditure incentives for geothermal energy totaled approximately $2 billion.

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

c. R&D. Through 2016, federal R&D spending for geothermal energy totaled $6 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 $2 billion through 2016.

f. Disbursements. Federal disbursements to encourage geothermal energy totaled approximately $1 billion through 2016.

Appendix 4 – Current and Constant Dollar Estimates

This analysis spans a period of 66 years (1950–2016), during which the general price level in the United States increased eight-fold. 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 expenditures over this period is to use values expressed in constant dollars. It would be misleading to equate a dollar expended in 1973 with one spent in 2016, since the price level in the latter year is more than four 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 2015 dollars.

The authors derived the constant 2015 dollar data (2015 = 1.00) using GDP deflators to convert current dollar data into 2015 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 (CPI) deflators.

The CPI 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 (BLS) 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 CPI 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 CPI.

The implicit price deflator (IPD), compiled by the Bureau of Economic Analysis (BEA) 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 CPI 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 CPI is restricted to a narrower universe. The movement of the IPD usually closely parallels the movement of the CPI but is rarely identical to it. The implicit GDP deflators are the ones used in this study, and the deflators for 1950–2016 are listed in Exhibit 12.

Exhibit 12 – U.S. Gross Domestic Product Deflators Used
(2015 = 100)

YEAR	GDP DEFLATOR	YEAR	GDP DEFLATOR	YEAR	GDP DEFLATOR
1950	12.50	1972	22.71	1994	67.08
1951	13.38	1973	23.94	1995	68.48
1952	13.61	1974	26.09	1996	69.73
1953	13.78	1975	28.51	1997	70.92
1954	13.91	1976	30.08	1998	71.69
1955	14.15	1977	31.94	1999	72.79
1956	14.63	1978	34.18	2000	74.44
1957	15.12	1979	37.01	2001	76.14
1958	15.45	1980	40.34	2002	77.31
1959	15.67	1981	44.11	2003	78.85
1960	15.89	1982	46.85	2004	81.02
1961	16.06	1983	48.70	2005	83.63
1962	16.26	1984	50.42	2006	86.20
1963	16.44	1985	52.04	2007	88.49
1964	16.70	1986	53.09	2008	90.23
1965	17.00	1987	54.44	2009	90.91
1966	17.48	1988	56.35	2010	92.02
1967	17.99	1989	58.54	2011	93.92
1968	18.75	1990	60.70	2012	95.65
1969	19.68	1991	62.72	2013	97.20
1970	20.71	1992	65.68	2014	98.94
1971	21.77	1993	65.68	2015	100.00

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 66 years. The major challenges in deriving these data included the following:

- The R&D expenditures involved spanned nearly seven 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— sometimes significantly—on almost a year-by-year basis.
- Individual R&D programs and subprograms were continually redefined, reclassified, disaggregated, and re-aggregated.
- 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.
- The budget expenditures for a specific detailed program for a given year often 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 periods 1950-1975 and 1976-2016, with most of the analysis and budget detail devoted to the latter period.

As noted here, 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 1976-2016 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 2016 would not be available until the DOE and the OMB budget documents are available for 2017 or 2018. 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. Early development 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 2015, nuclear energy produced 19.5 percent of U.S. electricity and supplied approximately eight 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, SMR licensing technical support, reactor concept R,D,&D, 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
- nuclear energy enabling technologies
- the breeder program
- remedial action
- university programs
- SMR licensing technical support
- reactor concept R,D,&D
- nuclear Hydrogen Initiative
- advanced Nuclear Medicine Initiative
- advanced test reactor fusion irradiation
- civilian waste R&D. civilian waste R&D.
- program direction
- policy and management and miscellaneous
- Generation IV nuclear energy systems
- SMR licensing technical support

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 $42.3 billion (2015 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 quarter century 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, $28.2 billion was spent on nuclear reactor R&D, but only $2.4 billion (8.5 percent) of these funds were expended on LWR research.

Exhibit 13 – Nuclear Reactor Research and Development Expenditures, 1950–1962
(Millions of 2015 Dollars)

PROGRAM	EXPENDITURES
Civilian Nuclear Power Reactors	5,712
Light Water Reactors	
Pressurized Light Water	1,774
Boiling Light Water	638
Heavy Water	374
Organic Moderated	443
Gas Cooled	677
Sodium Cooled	1,734
Other Studies and Development	70
Army Reactors	546
Naval Reactors	7,655
Merchant Ship Reactors	334
Missile and Space Propulsion	1,837
Aircraft Propulsion	3,673
Auxiliary Power Sources	769
General	7,633
TOTAL	28,156

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 ($33.6 billion out of $177.3 billion—about 19 percent), and expenditures for light water reactor research were a small portion of reactor R&D funds—$1.6 billion out of $36.6 billion, about four 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

[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.

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—$8.9 billion out of $36.6 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 2015 dollars)

	FY63	FY64	FY65	FY66	FY67	FY68	FY69	FY70	FY71	FY72	FY73	FY74	FY75	Total
Nuclear Materials	7,422	6,233	5,281	4,623	4,086	3,623	3,261	2,785	2,540	2,536	2,648	2,759	1,495	49,293
Weapons Development	4,579	5,204	4,844	4,506	4,402	4,493	4,915	4,672	4,651	4,559	4,375	3,892	2,044	57,134
Development of Nuclear Reactors	3,339	3,645	3,416	3,021	3,160	3,145	2,781	2,677	2,556	2,480	2,496	2,418	1,448	36,581
Light Water Reactors	205	285	236	192	210	137	109	78	60	61	36	13	9	1,629
Breeder Reactors	131	317	469	519	599	778	706	665	692	835	1,127	1,022	1,005	8,870
All Other Reactors	3,003	3,043	2,709	2,309	2,352	2,230	1,966	1,933	1,804	1,583	1,334	1,383	433	26,082
Physical Research	1,308	1,398	1,506	1,636	1,747	1,777	1,817	1,746	1,620	1,355	1,536	1,549	686	19,678
Biomedical and Environmental Research	467	498	539	562	568	567	541	562	524	526	555	584	356	6,851
Administration, Regulation and Misc.	709	750	731	717	677	762	728	573	469	752	405	100	380	7,752
Total Cost of Operations	17,825	17,730	16,315	15,064	14,641	14,365	14,043	13,013	12,360	12,208	12,014	11,300	6,407	177,286

Exhibit 15 – Summary of Federal R&D Expenditures for Nuclear Energy, 1950–2016

(Billions of 2015 dollars)

	1950–1975	1976–2016	Total 1950–2016
Light Water Reactor R&D	4.1	4.5	8.6
Breeder R&D	10.8	17.0	27.8
Other Nuclear Energy R&D	30.8	17.6	48.4
Total	45.7	39.1	84.8

Exhibit 15 summarizes federal R&D expenditures for nuclear energy, 1950–2016. Exhibits 16 and 17 show the components of the ERDA/DOE nuclear energy R&D program for the years 1976-1997; Exhibit 18 shows federal nuclear energy R&D expenditures for 1998–2003; Exhibit 19 shows federal nuclear energy R&D expenditures for 2004–2010; and Exhibit 20 shows federal nuclear energy R&D expenditures for 2011–2016. The authors estimate that the federal government spent $84.8 billion (2015 dollars) on commercial nuclear energy R&D through 2016 (Exhibits 13–20). 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 (FFTR), and basic R&D.

The data primarily reflect 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, 1976–1986

(Millions of 2015 dollars)

	FY76	76tq	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86
Nuclear Energy R&D	2,223	675	2,996	3,348	3,293	2,968	2,770	2,724	1,794	1,429	855	750
Commercial Nuclear Waste	120	64	392	392	563	593	730	546	92	55	---	---
Spent Nuclear Fuel	---	---	---	15	33	33	54	---	---	---	---	---
Converter Reactor Systems	163	83	229	305	353	175	166	237	174	197	327	96
Light Water Reactor	8	12	35	41	71	78	104	124	85	114	104	96
Other Converter Reactor Systems	155	71	195	264	281	97	62	113	89	83	223	---
Advanced Nuclear System	141	42	143	195	161	105	111	98	85	71	57	252
Facilities[1]	---	---	---	---	---	---	---	---	---	---	---	263
Advanced Radioisotope Power System	---	---	---	---	---	---	---	---	---	---	---	40
Space Reactor Power System	---	---	---	---	---	---	---	---	---	---	---	40
Nuclear Fuel Cycle	---	---	---	---	---	---	---	134	93	---	---	---
Breeder Program	1,799	486	2,231	2,440	2,184	2,025	1,708	1,616	1,211	897	405	35
Remedial Action	---	---	---	---	---	---	---	93	138	210	---	---
University Reactor Fuel Asst. & Support	---	---	---	---	---	---	---	---	---	---	---	---
Advanced Test Reactor Fusion Irradiation	---	---	---	---	---	---	---	---	---	---	---	---
Program Direction	---	---	---	---	---	37	---	---	---	---	62	21
Policy Management & Misc.	---	---	---	---	---	---	---	---	---	---	4	---
Civilian Waste R&D	---	---	---	---	---	---	---	---	---	23	53	30
Total Nuclear Energy Supply R&D	2,223	675	2,996	3,348	3,293	2,968	2,770	2,724	1,794	1,453	907	780

Exhibit 17 – Federal R&D Expenditures for Nuclear Energy, by Major Program, 1987–1997

(Millions of 2015 dollars)

	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	Total 76–97
Nuclear Energy R&D	634	652	635	587	504	524	539	360	335	215	186	30,995
Commercial Nuclear Waste	---	---	---	---	---	---	---	---	---	---	---	3,550
Spent Nuclear Fuel	---	---	---	---	---	---	---	---	---	---	---	134
Converter Reactor Systems	65	61	51	41	63	102	92	89	93	57	53	3,273
Light Water Reactor	65	61	51	41	63	102	92	89	93	57	53	1,641
Other Converter Reactor Systems	---	---	---	---	---	---	---	---	---	---	---	1,632
Advanced Nuclear System	146	174	137	102	93	93	93	64	61	37	27	2,491
Facilities	248	222	246	292	153	158	147	49	37	23	21	1,857
Advanced Radioisotope Power System	40	39	68	84	124	82	84	82	90	70	53	852
Space Reactor Power System	92	140	118	53	54	64	48	41	1	---	---	653
Nuclear Fuel Cycle	---	---	---	---	---	---	---	---	---	---	---	228
Breeder Program	25	---	---	---	---	---	---	---	---	---	---	17,067
Remedial Action	---	---	---	---	---	---	---	---	---	---	---	441
University Reactor Fuel Asst. & Support	---	---	---	---	---	---	---	---	5	4	5	14
Advanced Test Reactor Fusion Irradiation	---	---	---	---	---	---	---	---	4	2	1	8
Program Direction	15	16	14	15	16	26	22	16	21	10	13	306
Policy Management & Misc.	---	---	---	---	---	---	53	18	22	12	13	121
Civilian Waste R&D	13	10	4	1	1	9	8	1	1	---	---	155
Total Nuclear Energy Supply R&D	647	662	639	588	506	534	548	361	336	215	186	31,151

Exhibit 18 – Federal R&D Expenditures for Nuclear Energy, by Major Program, 1998–2003

(Millions of 2015 dollars)

	FY98	FY99	FY00	FY01	FY02	FY03	Total 98-03
University Reactor Infrastructure and Education Assistance	11	15	16	15	24	24	105
Nuclear Energy Plant Optimization	---	---	5	5	9	5	25
Nuclear Energy Research Initiative	---	26	29	36	28	23	142
International Nuclear Energy Research Initiative	---	---	---	10	12	9	30
Next Generation Nuclear Plant	---	---	---	---	---	3	3
Generation IV R&D	---	---	---	4	4	11	20
Nuclear Power 2010	---	---	---	3	11	41	55
Civilian R&D (ATW)	---	---	11	---	---	---	11
Nuclear Hydrogen Initiative	---	---	---	---	---	2	2
Isotope Support	27	30	26	---	---	---	84
Advanced Radioisotope Power Systems	57	52	40	---	---	---	149
Advanced Nuclear Medicine Initiative	---	---	---	3	---	---	3
Advanced Fuel Cycle Initiative	---	---	---	---	101	73	174
Test Reactor Area Landlord	11	11	---	---	---	---	22
Program Direction	11	13	14	5	15	16	75
Total DOE Nuclear Energy Supply R&D	115	147	142	85	203	206	899

Exhibit 19 – Federal R&D Expenditures for Nuclear Energy, 2004–2010

(Millions of 2015 dollars)

	FY04	FY05	FY06	FY07	FY08	FY09	FY10	Total 04-10
University Reactor Infrastructure and Education Assistance	28	29	28	20	---	5	5	116
Nuclear Energy Plant Optimization	3	3	---	---	---	---	---	7
Nuclear Energy Research Initiative	7	3	0	---	---	---	---	10
Generation IV R&D	34	48	53	40	128	200	240	743
Nuclear Power 2010	24	61	65	92	150	197	115	704
Nuclear Hydrogen Initiative	7	11	24	22	11	9	---	83
Advanced Nuclear Medicine Initiative	163	150	16	---	---	---	---	329
Advanced Fuel Cycle Initiative	83	83	83	190	---	162	149	749
Program Direction	24	25	13	35	25	52	47	221
Total DOE Nuclear Energy Supply R&D	372	413	281	399	314	625	556	2,960

Exhibit 20 – Federal R&D Expenditures for Nuclear Energy, 2011–2016

(Millions of 2015 dollars)

	FY11	FY12	FY13	FY14	FY15	FY16	Total, FY11-16
Integrated University Program	-	5	5	6	5	5	26
SMR Licensing Technical Support	-	70	65	111	55	62	363
Reactor Concept R,D, & D	175	116	108	114	133	141	787
Fuel Cycle R&D	194	189	175	188	197	202	1,145
Nuclear Energy Enabling Technologies	54	75	70	72	101	111	483
Radiological Facilities Management	55	73	67	25	25	24	269
International Nuclear Energy Cooperation	3	3	3	3	3	3	18
STEP R&D	-	-	-	-	5	5	10
Program Direction	73	76	72	73	66	65	425
Total DOE Nuclear Energy Supply R&D	554	607	565	592	590	618	3,526

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 $470 million (2015 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 radioactive materials, neutron diffusion codes, critical experiment technology, and other information were largely applicable to the commercial program.

The commercial program, however, 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 1976–2016, the authors find:

- The commercial nuclear energy R&D program peaked at $3.4 billion in 1978 and declined steadily thereafter, reaching a low of $85 million in 2001. The trend in federal spending on nuclear energy R&D is shown in Exhibit 8 on page 16.
- Since 1976, less than 12 percent of the total of $39.1 billion in nuclear energy R&D expenditures has been devoted to LWRs.

- Of the total nuclear R&D expenditures 1976-2016, 44 percent ($17 billion), was devoted to the breeder program. Since 1950, the breeder program consumed 33 percent—$27.8 billion of $84.8 billion—of civilian nuclear energy R&D, and nearly 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 $4.5 billion (11.5 percent) of the $39.1 billion total R&D expenditures, 1976-2016. 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.

Appendix 7 – Coal R&D Expenditures

A. Background

The U.S. has relied on coal as a major energy source for two centuries, and it currently provides nearly 40 percent of the nation's electricity and about one-fifth 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 seven 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 (BOM) 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 market for coal (aside from exports) is the electric utility industry, which is meets 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 and carbon dioxide.

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 EPA—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 capture and 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 continued use of U.S. coal 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. The current program emphasizes carbon capture and storage (CCS) and activities that increase the efficiency and availability of systems integrated with CCS.

In FY 2016, no new funding was requested for CCS demonstrations. Initial efforts to address the technical challenges inherent to capture from a gas-fired power facility, such as a lower concentration of CO_2 and higher oxygen content, began in FY 2016 through the Carbon Capture program in preparation for a future demonstration facility. The program is committed to delivering a demonstration project that captures and stores more than 75 percent of the carbon emissions from a natural gas power system of at least 50 MWe capacity by 2020 using what has been determined to be the best available carbon capture technology available for demonstration at the time.

Carbon Capture maintains priority on post-combustion and pre- combustion capture for fossil fuel-fired plants. Carbon Capture funding supports a new emphasis on optimizing carbon capture on natural gas systems and the transition and scale-up of multiple, advanced CO_2 capture technologies, including support for up to two large-scale pilot projects (10+ MWe) to reduce costs and validate performance and operation for both coal and natural gas-fired power plants. Carbon Storage funding supports storage infrastructure projects to validate and increase certainty of carbon storage, including Regional Carbon Sequestration Partnerships (RCSPs), and fit-for-purpose injection tests. Funding for Advanced Storage R&D develops technologies and tools to better quantify and assess risk and uncertainty of storage and improved monitoring tools and technologies. Sub-Disciplinary R&D increases funding for Energy Data Exchange (EDX) and the National Risk Assessment Partnership (NRAP) to expand capabilities and tool sets to enhance efforts on data management and surety of storage.

The Advanced Energy Systems (AES) program is designed to increase the availability and efficiency of fossil energy systems integrated with CO_2 capture, while maintaining the highest environmental standards at the lowest cost. Advanced Combustion Systems focusses on the development of advanced combustion technologies, such as pressurized oxy-combustion and chemical looping processes, which have the potential to achieve a capture cost of $40/ton. Materials development for advanced turbines and advanced gasification technology developments focuses on air separation, gas clean up, and fuel feed systems. Work on Solid Oxide Fuel Cells maintains the Program's long-term focus on coal or natural gas fueled central station generation.

Cross Cutting Research supports R&D in modeling and simulation, materials, Energy-Water Nexus, sensors and controls, and university research. These activities serve as the scientific foundation for research development and deployment (RD&D) of technologies at various stages of development within Carbon Capture, Carbon Storage, and Advanced Energy Systems. Plant Optimization Technology funds advanced ultra-supercritical materials R&D, water management research and development, sensors and controls, and cross-cutting materials R&D. The program also supports activities in Coal Utilization Science and Focus Area for Computational Energy Science, both of which support data handling and optimization to improve the design and operation of advanced power systems with carbon capture and sequestration. The program provides first principle and physics-based modeling of phenomenon for complex energy conversion and carbon capture processes.

The Supercritical Carbon Dioxide Technology (SCO_2) subprogram within the CCS and Power Systems supports DOE's crosscut, SCO_2, which is focused on technology development for supercritical carbon dioxide-based power conversion cycles. These cycles can be applied to most heat sources, including fossil, nuclear, solar, and geothermal applications, while offering significant improvements in efficiency, cost, footprint, and water use. DOE's ultimate goal is a directly-fired supercritical CO_2 fuel cycle which could also significantly reduce the costs of carbon capture and storage. The major thrusts of the crosscut are a coordinated R&D effort in high temperature technology development/component validation, and the Supercritical Transformational Electric Power Generation (STEP) initiative to design, construct, and operate a 10-MW pilot test bed.

The Clean Coal Technology Program was established in the 1980s to perform commercial-scale demonstrations of advanced coal-based technologies. All projects have concluded and only closeout activities remain.

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
- advanced turbines
- advanced energy systems
- supercritical CO_2 technology
- program direction and management support
- 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 21, which illustrates that, over the 26-year period, the federal government invested $6 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.

Exhibits 22 through 28 show the detailed federal coal R&D programs undertaken at ERDA, DOE, EPA and BOM between 1976 and 2016. Over this period, coal R&D expenditures totaled $36.6 billion, as summarized in Exhibit 28. They increased rapidly from 1976 through 1980, reaching an all-time high of $2.7 billion in 1980, as shown in Exhibit 22. Expenditures decreased slightly to $2.5 billion in 1981, and then decreased drastically, falling by nearly three-quarters to less than $700 million by 1984. Thereafter, coal R&D expenditures remained relatively constant until 1990 and then decreased gradually thereafter, declining to $323 million in 1997—at which time they were, in real terms, only 12 percent of their 1980 total. By 2004, however, coal R&D funding had increased to nearly $800 million and to nearly $900 million in 2009 — the highest level in more than three decades. In 2016, coal R&D expenditures totaled $542 million.

Exhibit 21 – Summary of Federal R&D Expenditures for Coal, 1950–1975

(Millions of 2015 dollars)

Year	Expenditures	Year	Expenditures
1950	101	1963	121
1951	95	1964	125
1952	95	1965	115
1953	93	1966	127
1954	74	1967	150
1955	61	1968	181
1956	66	1969	165
1957	73	1970	196
1958	87	1971	327
1959	85	1972	473
1960	101	1973	707
1961	118	1974	981
1962	117	1975	1,339

Exhibit 22 – Federal R&D Expenditures for Coal, by Major Program, 1976–1988

(Millions of 2015 dollars)

	FY76	76tq	FY 77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88
U.S. DOE	1,192	306	1,597	1,844	2,053	2,110	1,956	1,098	522	444	474	460	380	413
Control Technology & Coal Preparation	--	--	--	--	--	--	--	57	62	55	74	64	74	83
Advanced Research & Technology Development	127	33	149	160	135	163	123	128	79	83	83	65	62	48
Coal Liquefaction	355	92	378	354	606	578	815	525	84	62	53	64	48	50
Combustion Systems	167	50	190	216	174	202	149	93	53	39	62	57	28	48
Heat Engines	--	--	--	--	172	170	111	35	12	14	25	25	23	35
Magnetohydrodynamics	123	33	137	229	176	218	197	64	64	64	63	55	53	65
Surface Coal Gasification	281	57	488	673	472	460	266	123	85	79	65	82	49	42
Underground Coal Gasification	--	--	--	--	43	27	25	18	13	13	15	9	4	5
Mining Research & Development	--	--	176	197	224	181	105	26	--	--	--	--	--	--
Advanced Environmental Control Tech	--	--	--	--	21	64	123	--	--	--	--	--	--	--
Program Direction & Management Support	--	--	--	--	29	33	29	27	70	35	35	39	40	37
Miscellaneous	138	42	78	15	--	13	13	--	--	--	--	--	--	--
U.S. EPA	256	83	410	380	391	418	415	198	114	134	172	166	168	163
Bureau of Mines	242	57	279	300	229	181	141	109	85	118	90	77	91	89
Total Coal Energy R&D	1,691	446	2,286	2,523	2,673	2,710	2,512	1,404	722	697	736	703	640	666

Exhibit 23 – Federal R&D Expenditures for Coal, by Major Program, 1989–1997

(Millions of 2015 dollars)

	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	Total 76-97
U.S. DOE	431	446	446	401	331	291	242	270	173	17,878
Control Tech & Coal Preparation	89	100	92	82	67	70	62	50	42	1,121
Advanced Research & Technology Development	48	43	51	49	42	43	36	29	25	1,806
Coal Liquefaction	57	61	71	63	58	39	39	22	14	4,489
Combustion Systems	49	57	62	62	58	70	63	63	45	2,057
Heat Engines	41	36	40	28	5	--	--	--	--	770
Magnetohydrodynamics	67	68	65	64	48	8	--	--	--	1,864
Surface Coal Gasification	40	40	25	16	16	25	15	12	10	3,421
Underground Coal Gasification	1	1	1	--	--	--	--	--	--	176
Mining Research & Development	--	--	--	--	--	--	--	64	8	982
Advanced Environmental Control Tech	--	--	--	--	--	--	--	--	--	208
Program Direction & Mgt. Support	40	39	37	36	36	37	27	28	28	682
Miscellaneous	--	--	--	--	--	--	--	--	--	300
U.S. EPA	154	141	134	151	149	140	124	186	151	4,799
Bureau of Mines	96	92	96	92	91	96	89	5	--	2,746
Total Coal Energy R&D	681	680	675	643	572	527	454	460	323	25,426

Exhibit 24 – Federal Coal R&D, 1998–2000

(Millions of 2015 dollars)

	FY98	FY99	FY00	Total 98–00
U.S. DOE	253	288	284	825
Advanced Electric Power Systems	97	122	106	325
Advanced Pulverized Coal Technology	24	20	2	46
Indirectly Fired Cycle	5	11	10	26
Gasification Combined Cycle	30	45	47	122
Pressurized Fluid Bed	26	20	16	62
Advanced Research and Environmental	17	27	32	76
Advanced Clean Fuel Research	21	22	26	68
Coal Preparation	5	5	4	15
Coal Liquefaction	10	13	10	33
Steelmaking Feedstock	4	-	10	14
Advanced Research and Environmental	1	2	2	5
Advanced Research and Tech Development	26	28	30	85
Fuel Cells	57	61	61	178
Miscellaneous R&D	10	10	9	28
Program Direction and Management Support	43	46	51	140
U.S. EPA Coal R&D	156	162	137	455
Total Federal Coal R&D	410	450	421	1,280

Exhibit 25 – Federal Coal R&D, 2001–2003

(Millions of 2015 dollars)

	FY01	FY02	FY03	Total 01–03
U.S. DOE	521	616	616	1,753
Clean Coal Power Initiative	---	190	186	376
Central Systems	265	122	118	505
Innovations for Existing Plants	27	29	28	85
Advanced Systems				
Integrated Gasification Combined Cycle	55	55	55	166
Pressurized Fluidized Bed	15	14	13	42
Turbines	41	24	22	87
Power Plant Improvement Initiative	126	---	---	126
Sequestration	26	41	50	117
Fuels	30	43	39	113
Transportation Fuels and Chemicals	11	33	27	71
Solid Fuels and Feed stocks	4	5	9	18
Advanced Fuels Research	5	4	3	13
Steelmaking	10	---	---	10
Advanced Research	39	40	41	121
Coal Utilization Science	9	9	12	29
Materials	10	10	12	32
Technology Crosscut	16	14	14	45
Other Advanced Research	4	9	3	16
Fuel Cells	71	74	75	220
Miscellaneous R&D	13	18	18	50
Program Direction and Management Support	77	88	89	254
U.S. EPA Coal R&D	130	129	117	377
Total Federal Coal R&D	650	745	734	2,129

Exhibit 26 – Federal Coal R&D, 2004–2010

(Millions of 2015 dollars)

	FY04	FY05	FY06	FY07	FY08	FY09	FY10	Total 04–10
U.S. DOE	677	511	528	553	632	851	505	4,258
Clean Coal Power Initiative	212	58	59	67	77	319	---	792
Central Systems	112	95	116	---	---	---	---	323
FutureGen	---	---	---	61	83	---	---	143
Innovations for Existing Plants	---	---	---	18	40	54	57	170
Advanced IGCC	---	---	---	63	61	70	68	262
Advanced Turbines	---	---	---	111	134	162	168	575
Sequestration	50	53	78	22	27	30	35	296
Fuels	39	37	34	25	28	26	27	216
Fuel Cells	86	90	73	72	62	62	54	499
Advanced Research	47	50	45	37	41	30	30	280
Program Direction and Management Support	131	127	124	77	79	98	64	701
U.S. EPA Coal R&D	116	105	102	14	15	18	16	388
Total Federal Coal R&D	793	616	630	567	649	869	522	4,647

Exhibit 27 – Federal Coal R&D, 2011–2016
(Millions of 2015 dollars)

	FY11	FY12	FY13	FY14	FY15	FY16	Total FY 11–16
U.S. DOE							
Carbon Capture	62	70	66	90	88	100	476
Carbon Storage	128	117	110	107	100	105	667
Advanced Energy Systems	179	102	95	101	103	104	684
Cross Cutting Research	44	50	47	42	49	50	282
Supercritical CO_2 Technology	-	-		-	10	15	25
NETL Coal R&D	-	37	43	51	50	52	233
Program Direction and Management Support	157	113	102	106	104	101	683
U.S. EPA Coal R&D	18	16	16	15	15	15	95
Total Federal Coal R&D	588	505	479	512	519	542	3,145

Exhibit 28 – Federal Coal R&D, 1976–2016
(Millions of 2015 dollars)

	76–97	98–00	01–03	04–10	11-16	Total
U.S. DOE	17,881	825	1,752	4,259	3,050	27,767
U.S. EPA Coal R&D	4,799	455	377	388	95	6,114
BOM	2,746	--	--	--	--	2,746
Total Federal Coal R&D	25,426	1,280	2,129	4,647	3,145	36,627

Note: The BOM ceased operations in 1996.

D. Major Findings

Focusing on the period 1976–2016, the authors find that:

- The largest share of R&D funds was allocated to environment-related coal research programs at EPA and, when combined with the environmental research programs within DOE, environmental research accounted for about 24 percent ($8.9 billion) of the R&D budget.
- Coal liquefaction received the second largest share of the coal R&D budget—12 percent ($4.5 billion).
- R&D expenditures for surface coal gasification totaled $3.3 billion— nine percent of the total.
- The research program at the BOM, which consisted of a variety of coal-related research programs, expended $2.7 billion over this period—seven percent of the total.
- Research spending on combustion systems totaled $4.1 billion (11 percent of the total), and spending on magnetohydrodynamics totaled $1.7 billion (five percent of the total).
- In constant dollars, federal funding of coal R&D bottomed out in 1997 at $323 million; by 2009 coal R&D had increased to $869 (nearly three times its 1997 level), and in 2016 totaled $542 million (see Exhibit 8 on page 16).

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 nine percent of the nation's energy, mostly in the form of hydroelectricity, geothermal energy, and biomass in the wood products industry.

Of the $274 billion in federal energy incentives for hydroelectric power, geothermal energy, and renewables, $40 billion were in the form of R&D expenditures, $32 billion of which were expended on solar, wind, and biomass.[11] Therefore, when discussing R&D funding in this study, renewable energy is defined narrowly to include solar energy, wind, biomass, 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.[12]

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.[13] 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.

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[11]See Table 1 in Section IV of this report.

[12]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.

[13]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, and this emphasis increased further after 2009 during the Obama Administration.

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 bioenergy 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 $2.3 billion (2015 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—$800 million
- National Science Foundation—$600 million
- AEC—$200 million
- USDA—$300 million
- All other federal agencies—$400 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 ($704 million in 2015 dollars) on renewable energy (excluding hydroelectric power and geothermal energy).[14]

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.[15] 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 29 summarizes expenditures for renewable energy research from 1976 to 2016.

Exhibit 29 – Federal Renewables R&D, 1976–2016
(Millions of 2015 dollars)

	76-97	98-03	04-06	07-10	11-16	Total
DOE	15,082	2,578	1,461	2,994	5,166	27,280
USDA	661	186	143	235	317	1,542
NASA	223	34	24	48	141	469
Total	15,964	2,797	1,628	3,276	5,624	29,291

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

Exhibits 30 through 33 show the program details for the renewable energy program from 1976 to 2016. As noted previously, total federal R&D expenditures on renewables through 1975 were approximately $2.3 billion. Most of this R&D was conducted by NSF, AEC, NASA and USDA. Through 2016, total federal R&D funding for renewables was about $32 billion, with nearly 95 percent of the funding occurring after 1975.

The renewable energy R&D program grew very rapidly during the 1970s, from about $53 million per year in 1972 to nearly $2 billion annually by 1981. Program funding peaked in 1981 and then declined rapidly and substantially. Funding in 1982 ($836 million) was less than half that of the previous year, and by 1990 it reached a low point of $265 million—in real terms less than half of what it had been in 1976. Since 1990, funding for the program has more than tripled, reaching $913 million in 2016.

Exhibit 30 – Federal R&D Expenditures for Renewable Energy, by Major Program, 1976–1986

(Millions of 2015 dollars)

	FY76	76tq	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86
Solar Energy	417	127	797	957	1,504	1,566	1,574	617	444	381	366	288
Solar Buildings Technology Research	130	38	92	95	264	231	167	52	27	35	21	15
Photovoltaic Energy Systems	79	26	200	240	351	394	343	171	127	105	117	80
Solar Thermal Energy Systems	101	26	304	308	341	383	289	122	109	92	71	51
Biofuels Energy Systems	17	8	35	66	123	150	155	71	45	60	63	53
Wind Energy Systems	51	17	71	110	175	168	196	78	67	57	60	50
Ocean Energy Systems	22	8	48	110	121	123	95	43	24	13	9	10
International Solar Energy Program	--	--	--	--	--	--	37	9	22	1	1	5
Solar Technology Transfer	8	4	48	28	41	64	101	23	8	5	13	5
National Renewable Energy Lab	--	--	--	--	--	17	24	--	--	--	--	4
Program Support	--	--	--	--	--	12	16	--	2	1	1	1
Resource Assessment	--	--	--	--	--	--	--	--	--	--	--	1
Program Direction –Other Solar Energy	8	--	--	--	88	22	149	49	13	13	10	10
Electric Energy Systems	32	14	48	92	93	100	98	49	37	40	42	24
Energy Storage Systems	58	22	109	187	189	178	178	87	57	55	38	35
Solar/Renewables R&D in Conservation	12	4	24	28	41	49	57	23	22	23	24	24
DOE Solar/ Renewables Tech. Base	518	166	977	1,265	1,828	1,892	1,905	776	560	499	471	372
USDA Solar/ Renewables R&D	17	8	30	36	36	37	48	49	50	42	38	28
NASA Solar/ Renewables R&D	17	4	16	15	14	13	13	12	12	10	10	10
Total Federal Solar/Renewables R&D	554	178	1,024	1,316	1,878	1,942	1,965	836	621	552	519	410

Exhibit 31 – Federal R&D Expenditures for Renewable Energy, by Major Program, 1987–1997

(Millions of 2015 dollars)

	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	Total
Solar Energy	240	179	164	153	209	280	292	383	383	292	266	11,879
Solar Buildings Technology Research	12	10	9	1	2	2	4	8	5	2	2	1,228
Photovoltaic Energy Systems	78	65	65	62	77	95	102	121	125	88	84	3,195
Solar Thermal Energy Systems	43	30	27	26	30	48	42	51	43	35	30	2,604
Biofuels Energy Systems	48	30	23	27	53	63	75	89	77	77	77	1,487
Wind Energy Systems	32	16	15	15	17	35	37	45	66	45	41	1,468
Ocean Energy Systems	10	8	8	8	4	2	1	1	0	0	0	667
International Solar Energy Program	1	1	1	1	1	2	2	8	13	5	1	114
Solar Technology Transfer	5	5	4	2	2	1	2	30	21	15	0	437
National Renewable Energy Lab	1	1	1	1	9	21	12	9	9	1	4	115
Program Support	1	1	1	1	1	1	1	8	0	0	0	51
Resource Assessment	1	1	1	1	1	1	1	2	5	2	0	21
Program Direction –Other Solar Energy	8	8	8	8	8	9	10	10	17	21	27	494
Electric Energy Systems	22	28	42	30	45	50	50	75	53	48	38	1,151
Energy Storage Systems	32	28	23	21	22	12	15	9	8	2	5	1,368
Solar/Renewables R&D in Conservation	23	21	21	27	28	35	40	43	45	37	35	684
DOE Solar/ Renewables Tech. Base	317	256	250	231	303	376	397	511	489	379	344	15,082
USDA Solar/ Renewables R&D	26	24	26	24	23	26	17	21	21	16	16	661
NASA Solar/ Renewables R&D	10	10	9	9	9	9	4	4	4	4	4	223
Total Federal Solar/Renewables R&D	353	290	284	265	336	411	418	535	513	399	365	15,964

Exhibit 32 – Federal Renewable Energy R&D, 1998–2006

(Millions of 2015 dollars)

	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	Total 98-06
Solar Energy										
Solar Buildings Technology Research	3	4	2	4	3	4	10	7	9	47
Photovoltaic Energy Systems	90	99	88	100	92	93	90	91	88	832
Solar Thermal Energy Systems	25	24	20	18	16	5	3	3	3	118
Zero Energy Buildings	--	--	--	--	1	11	--	--	--	12
Biopower/Biofuels Energy Systems	84	100	93	114	115	111	115	106	86	925
Wind Energy Systems	46	47	43	54	50	54	49	49	52	444
International Renewable Energy Program	1	10	5	5	3	3	7	7	3	45
National Renewable Energy Laboratory	1	4	1	4	--	--	--	--	--	11
Program Support	--	--	5	4	1	1	9	7	2	29
Program Direction	15	18	18	20	20	12	21	24	23	171
Hydrogen R&D	24	30	32	36	39	48	100	114	116	539
Fuel Cells	--	--	--	--	--	--	78	90	99	267
Electric Energy Systems and Storage	60	57	50	70	89	92	--	--	--	417
Renewables R&D in DOE Conservation	13	14	39	32	47	36	--	--	--	180
USDA Renewables R&D	13	13	17	24	40	78	50	43	50	329
NASA Solar	4	4	5	5	5	9	7	9	9	58
Total Federal Solar/Renewables R&D	380	426	426	496	526	559	540	552	539	4,425

Exhibit 33 – Federal Renewable Energy R&D, 2007–2016

(Millions 2015 dollars)

	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	Total, FY07-16
DOE Renewable Energy											
Biomass & Bioenergy	179	226	240	240	192	204	191	234	225	225	2,156
Solar Energy	176	192	192	270	277	298	277	260	233	242	2,417
Wind Energy	52	68	60	87	84	96	88	89	107	95	826
International Renewable Energy Program	2	0	6	0	0	0	0	0	0	0	8
Strategic Programs	3	4	8	13	34	26	27	25	21	21	182
Program Direction	37	42	46	51	181	172	165	164	160	155	1,173
Hydrogen	234	242	184	190	102	105	99	94	97	101	1,448
Department of Agriculture Renewables R&D	54	57	62	66	68	50	49	50	50	50	556
NASA Solar R&D	8	9	13	18	23	24	23	24	23	24	189
Total Federal Solar/Renewables R&D	745	840	811	935	961	975	919	940	916	913	8,955

D. Major Findings

The authors find:

- The program receiving the largest share of research support between 1976 and 2016 was the biomass/biofuels program in DOE and USDA—$6.2 billion (21 percent of the total).
- The photovoltaics program received the second largest share of renewable energy R&D funds between 1976 and 2016—$5.6 billion (about 19 percent of the total).
- Since 1950, photovoltaics has received 19 percent of all renewable energy R&D expenditures—approximately $6.0 billion.
- The third largest share of R&D funds expended since 1976 was spent on the solar thermal systems program, which received $3.3 billion (11 percent of the total).
- Between 1976 and 2016, wind energy R&D programs received $3 billion—about 10 percent of total renewables R&D funding over this period. The trend in federal spending on renewables R&D is shown in Exhibit 8, page 16
- 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. Over the past decade, hydrogen research received nearly $1.5 billion – about 16 percent of federal renewables R&D spending.