Energy R&D

As Figure 5 shows, Germany's public sector support for energy R&D has declined sharply (by more than 45% in real terms to the 1998 level of $396 million) throughout the 1990s. The recent decline in support is the continuation of a trend that began in the mid-1980s (shown in Figure 6), when government-sponsorship for energy R&D crested at approximately $1.5 billion—more than three times its current level. Approximately 90% of the reduction in government support is attributable to the steep and continuous withdrawal of funding for nuclear fission research beginning in the mid-1980s. Thoughout the 1970s and early 1980s, fission research had constituted the largest component of the German energy R&D portfolio, but growing public opposition to nuclear power—particularly in the aftermath of the 1987 Chernobyl disaster—led to a significant change in the composition of the R&D portfolio. Rather than shifting the funds that had been devoted to fission research to other energy R&D program areas, however, the German government diverted funding away from energy R&D entirely.

In the 1990s, some portion of the funding formerly devoted to energy R&D have been used instead to help pay for reunification with the former East Germany, while some funds have been allocated to other policy and R&D priorities such as biotechnology and information technology. As Figures 5 and 6 show, even though Germany's public energy R&D portfolio now is relatively more diverse and balanced than it was previously, no energy R&D area has fared well over the past decade; in real terms, all energy R&D program areas are currently funded below their 1991 levels of support.

Figure 5. Federal Energy R&D Expenditures 1990-1998[i]

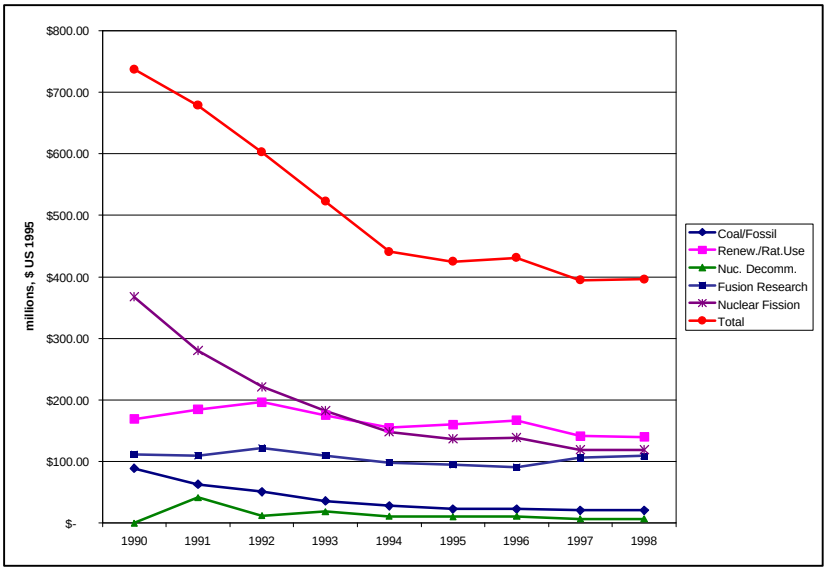
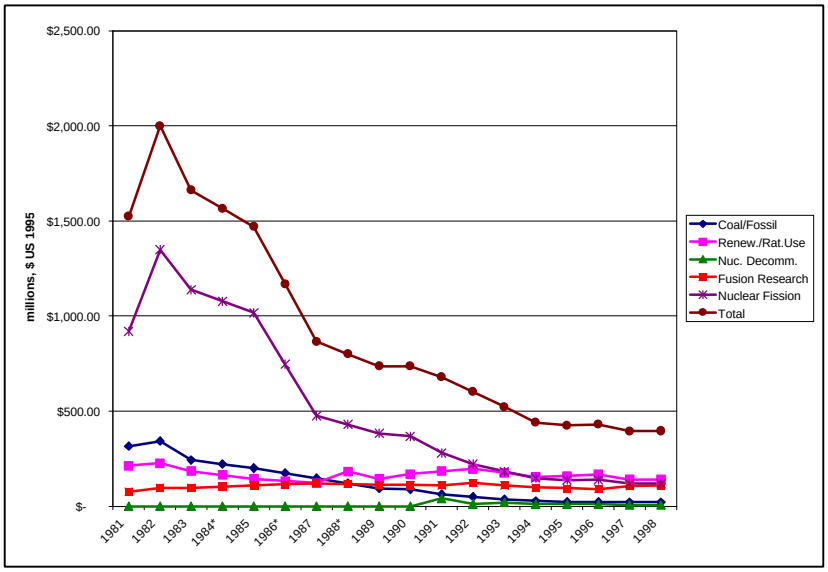


Figure 6. Federal Energy R&D Expenditures 1981-1998[ii1]



The German government's remaining energy R&D resources are allocated through the Fourth Energy Research and Technology Program, which began in fiscal 1996. The Program, which is administrerd by the BMBF will invest approximately $500 million annually between 1996-2000. The program has two major policy goals:

- To lay a broad technological foundation for the attainment of the federal government's carbon dioxide emissions reduction targets;
- To facilitate modernization of the German economy through the development of advanced energy technology products, and thereby to improve export opportunities for an important component of the German economy.

The Fourth Energy Research Program has the following major focus areas[iii]:

- Low CO_2 emitting combustion technologies and power plant designs that attain higher conversion efficiency in electricity production from hard and brown coal. Advances in this area will be applied in the reduction of Germany's overall energy demand and its domestic carbon emissions and are also aimed at capturing a larger portion of the growing world electric power market.[iv]
- Reduction of energy consumption in the second largest energy-consuming areas, space heating. Projects in this area focus on district heating, development of advanced solar thermal and passive solar technologies and construction techniques, and efficiency improvements in existing buildings through retrofits using new materials and efficiency technologies, particularly in residential buildings in the five new states.

[1] Data in Figure 6 for the years 1984, 1986, and 1988 are the author's interpolations.

- Industrial energy efficiency focusing on the development of energy-efficient processes and technologies that are broadly applicable across different industries, and on the transfer of technological advances from other technical areas and disciplines, such as materials science, biotechnology, and microtechnologies to the energy field.
- Further development of German wind energy capacity. Installed German wind energy capacity currently exceeds 2000MW and over 4000 turbines, generating over 4 billion kWh of power annually.
- Promotion of solar power as a long-term energy option. The BMBF's "Solar 2005" program aims to reduce the costs of solar cell production, specify the critical success factors for the broader use of solar PV technologies, and identify niche markets for photovoltaic devices and small energy systems.

The federal budget for renewable energy and energy efficiency grew by 10% (to $167 million) between 1994 and 1996—more than any other energy R&D area. Nonetheless, the 1996 funding level was still 15% below its 1992 peak of $196 million.[v]

Key Technology Areas[vi]

The German government, unlike governments in many other OECD countries, categorizes most of its energy R&D efforts according to the broad social goals the research activities seek to attain, rather than by the traditional technology areas (e.g., fossil, renewable, efficiency). Germany's federal energy R&D activities are organized around four major themes/objectives, which received a total budget of $431 million in 1996. Each of these objectives cross-cuts the traditional technology areas. For example, the first energy research objective, Reduction of Energy Use ($63.3 million), includes several fossil energy R&D programs, as well as fuel cell and hydrogen research, industrial efficiency, and district heating research. The second objective, Energy Supply for the Reduction of CO_2 Emissions and Environmental Impacts ($183.7 million), includes most renewable and nuclear fission energy R&D programs. Objective three, Long-term Energy Supply Options ($92 million), consists primarily of Germany's nuclear fusion R&D program. Objective four, Cross-cutting Themes ($9 million), includes a variety of activities such as energy systems analyses and information dissemination.

In keeping with the format of other case studies in this report and to facilitate easier comparison with other countries, Germany's federally funded energy R&D programs are presented here by standard technology area classification.

Energy Efficiency

The overall aim of programs in this area is the development of technologies that will permit the continuing reduction of energy demand and emissions of gases that could have damaging climatic effects. To this end, research focuses on efficiency gains in both energy conversion and in end use. The program also focuses on the development of solar

thermal heating particularly for its longer-term potential for the reduction of fossil fuel demand and for the use of decentralized buildings energy technologies. In addition to its potential for reducing energy demand, energy efficiency has relevance to Germany's economic policy, as it is viewed increasingly as a symbol of quality in both industrial machinery and consumer products. Thus, efficiency is an important element of Germany's productivity and international economic competitiveness. Government support for energy efficiency and renewable energy has remained essentially flat at approximately $167 million annually throughout the 1990s. Current estimates indicate, however, that 1997 and 1998 R&D expenditures in this area declined by nearly 15% to approximately $140 million.

Improvement of Industrial Energy Productivity *$4 million 1997*

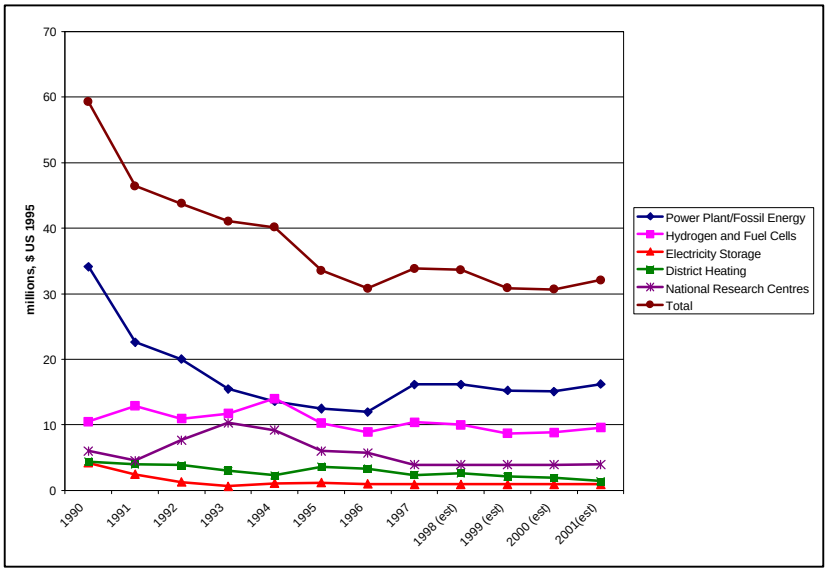
Research in this area has been a major part of previous government-sponsored energy research programs; consequently, the government believes a broad scientific and technical base exists as a foundation for future developments. Thus, funding for industrial efficiency has declined slightly in recent years. Among the diverse array of energy efficiency research projects sponsored are cross-cutting technologies that may be used in multiple branches of industry (e.g., cooling, compressed air production, pumps, and heat exchangers); interfaces with developments in other technical fields such as materials, sensors, microelectronics, lasers, and plasmas; simulation technologies to minimize expenditures on major experiments and to improve capacity for understanding of interactions in highly complex technical systems; systems analyses aimed at optimizing energy productivity in industrial processes; and energy-related biotechnology research (e.g., hydrogen production using biocatalysis). Under the Fourth Program for Energy Research and Technology, the federally sponsored industrial energy efficiency program has focused primarily on process efficiency, particularly in the electrolytic separation of metals, drying processes, and on the efficiency of industrial ovens.

Buildings Energy *$14 million 1997*

Space heating accounts for over half of household and other small consumers' energy use. Since over 80% of this demand is met using fossil fuels, the government believes this sector offers many opportunities for carbon dioxide emissions reduction through the substitution of renewable energy, particularly solar thermal technologies. Thus, Germany's energy research, as it relates to the household sector, has a strong focus in the solar thermal area. *Solar Optimized Construction,* which focuses on passive solar thermal building techniques, passive solar systems and components, and solar-optimized construction methods; *Energy Technologies for the Optimization of Future Buildings,* which aims to design residential buildings from a systems perspective aimed at minimizing energy use; *Renovation of Industrially Constructed Residential Buildings in the New States,* which aims to correct defects, hazards, and inefficiencies in the multi-unit, residential buildings of the east German states. Over 2.4 million of 7 million housing units in these five states are found in large, industrially constructed buildings.

Fossil Energy

Figure 7. German Government R&D Expenditures, Selected Fossil Energy Areas



District Heating. *$2 million 1997*
Germany's district heating research program recently underwent a major critical review and consolidation. Following extensive consultation with experts in the field, a new rationale was formulated for the program, now known as District Heating-2000. Several new research projects have been initiated under this program. District Heating-2000 has three areas of focus: (1) Research supporting the deployment of currently available technologies in existing systems; (2) Cross-cutting themes for mid-term R&D, such as creation of innovative heat distribution systems, process optimization, and cooling applications; and (3) Longer term possibilities for district heating, such as vacuum super insulated district heating ducts, combined solar and district heating, and mobile applications/heat transport via specialized rail vehicles.

Power Plant Technology and Combustion Research *$16 million 1997*
This research area has a broad scope, ranging from energy exploration, mining, and production, to power plant technology and coal liquefaction and gasification. Another major focus has been the attainment of higher levels of efficiency in German-manufactured gas turbines and their use in the construction of modern gas/steam turbine power plants. Planned research will focus on design of advanced steam power plants, combustion chambers, steam turbines and condensers, and on the development of corrosion-resistant materials. Through a number of government-industry consortia, cost-shared research projects focus on the development of combined cycle plants with integrated coal gasification, cyclone combustion, pressurized coal combustion and indirect combustion systems and on the improvement of processes and components for high-temperature gas and steam combined cycle plants.

Fuel Cells and Hydrogen Research *$10 million 1997*

Fuel cells and hydrogen technologies were part of the renewable energy research area in earlier programs. Given the growing importance of these technologies, however, a new research area devoted specifically to fuel cell and hydrogen technologies has been created. German government-sponsored fuel cell research currently focuses on two main projects conducted collaboratively by the industrial and scientific communities: (1) development of solid oxide fuel cell (SOFC) technology for deployment in the utility sector, particularly the development of fuel cells with capacity in the 0.2-5 mW range for distributed utility applications; and (2) development of proton exchange membrane (PEM) fuel cells for transportation applications. Higher efficiency levels and lower emissions of pollutants could make these low-temperature fuel cells suitable to power motor vehicles in some applications. Government-sponsored hydrogen R&D activities focus on the development of system components that will serve to improve the potential for hydrogen production (e.g., high-performance electrolysis), storage, and end use (for example, hydrogen motors, catalytic heating and cooling systems). Hydrogen research is currently viewed as fitting into the energy strategy as a long-term option.

Electricity Storage *$1 million 1997*

The storage of electricity presents key challenges to the heightened use of highly variable renewable energy sources; performance and cost considerations surrounding electricity storage systems also constrain the use of electric vehicles that could improve local air quality in many areas. The government believes that federal government support for research and development is especially necessary in these two technical areas, where markets have yet to be developed. Among the core themes of German government-sponsored R&D in this area are (1) augmenting the capacity of electricity storage devices, and (2) improving efficiency and lifespan using intelligent load management and advanced monitoring methods and devices. In the case of longer term seasonal thermal storage, the following focus areas have been identified: (1) ground storage, (2) aquifer storage, and (3) electrochemical storage options, such as zeolite/water systems. With regard to short-term storage, dynamic latent heat storage techniques show particular promise, as does metal hydride (MgH_2) thermochemical storage for temperatures between 300 and 500 degrees C. Short-term high temperature (500-700 degrees C) thermal energy storage methods may present opportunities for storage in high-temperature industrial processes and in solar power plants.

Transportation Energy[2]

The German government's sponsorship of transportation R&D has four primary areas of concentration. In the motor vehicle program, technologies under development include natural gas vehicles for urban use; electric motors; alcohol fuels, including methanol and ethanol; and hydrogen as an alternative fuel, as described earlier. In the transportation systems technology area, a primary research focus is on the potential for information and telecommunications technologies to reduce the environmental and infrastructure burdens.

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[2] Funding data for specific Transportation R&D activities in the Fourth Energy Research and Technology Program are not available. Transportation projects are funded by the German Federal Transportation Ministry (BMV), which spent a total of $119 million in 1996 on all ground transport R&D.

To this end, R&D efforts are focusing on vehicle navigation and guidance systems and on improving the availability to drivers of real-time traffic information. Research activities also are seeking ways to reduce traffic volume by making public mass transport options more attractive; improved rail and water transport modes, as alternatives to truck transport, for shipment of freight are also under consideration. With respect to air transport, research focuses on energy conservation through innovations in power plant technology, flight instruments and equipment such as advanced aerodynamic designs, flexible and lower-drag materials and laminates, and "active wing" technologies; and air traffic control systems.

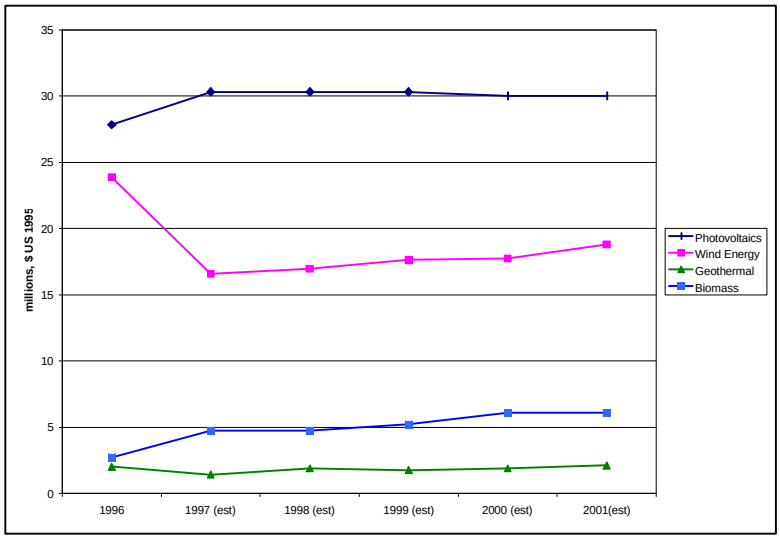
Renewable Energy

Renewable energy sources supplied approximately 2% of Germany's primary energy and some 5% of public utility-generated supply in 1994. The majority of this energy came from hydropower facilities, with the remainder generated through waste-to-energy and biomass plants. Wind energy represents only 0.3% of electric power supply, although its share continues to grow steadily. Solar photovoltaic accounts for a very small portion of energy supply (0.002% of electricity consumption is provided by some 3,000 grid-connected solar generators in 1994) because of its comparatively high costs. The government sees the present opportunities for deployment of solar technologies, for the most part, in niche markets where energy production cost is not the decisive criterion. In the previous energy research program, a new line of research was initiated focusing on the use of geothermal energy resources in the northern regions of the new states. The government, through the Federal Economic Ministry, has instituted a $50 million program focusing on the deployment of renewable energy technologies and through government-guaranteed low-interest loans for the purchase of renewable energy technologies.[vii] In general, government investments in renewable energy, shown in Figure 8, are shifting away from R&D and toward demonstration and deployment activities.

Photovoltaics *$28 million 1996*

Germany's solar photovoltaic R&D program concentrates on innovation in four areas of application: (1) off-grid commercial applications including telecommunications technologies (relay stations, transmitters), cathode corrosion prevention, traffic management technologies (signals, lighting, monitoring), and weather and environmental monitoring, (2) off-grid residential technologies, including rooftop solar power generation, local networks, and water pumps, (3) small system and consumer applications, and (4) grid-connected technologies for private residences, commercial buildings, and grid support. Additional activities will be carried out under the Photovoltaics 2005 Pioneer Program. Under this programR&D efforts fall into three categories: (1) Solar cell cost reduction through the reduction of manufacturing costs and efficiency improvements, (2) Cost reduction, technical optimization, and reduction of barriers to deployment in buildings applications; and (3) development of photovoltaic technologies for decentralized, off-grid power production.

Figure 8. Actual and Planned Government R&D Expenditures, Selected Renewable Energy Technology Areas 1996-2001



Wind Energy *$17 million 1997*

Several studies have shown that wind power has the potential to supply several percent of Germany's electricity supply. Considerable progress has already occurred in the development of commercially viable small and mid-sized wind generators. Further development of these technologies will be financed principally by wind turbine manufacturers themselves. To date, however, only prototypes of large generators (1 MW or more) have been built. Future government R&D efforts will aim to reduce the power production costs associated with larger turbines and installations (up to 250 MW), for instance by improving turbine lifespan and technical reliability, and by seeking to reduce turbine cost.

Biomass[viii] *$5 million 1997*

Biomass R&D activities sponsored by the German government focus on three major areas, all of which aim to improve and expand the longer term potential for the use of biomass-derived energy. With regard to biofuels production, activities include the continued development of environmentally sound agricultural techniques for the production of energy crops; improvement of harvest technologies; preparation and conditioning of energy crops and biofuels; and the solution of logistical problems associated with transport, storage, and delivery. Other research activities in this area address combustion optimization; biomass gasification and liquefaction; and combined use of fossil fuels and biofuels. A third area of focus, ecological research and evaluation, tracks the ecological balance of emissions and sequestration in all media associated with biomass programs and biomass energy use. The Federal Ministry of Agriculture and Forestry (BML), which has overall responsibility for renewable resources research, manages the government R&D efforts related to biomass energy.

Geothermal Energy *$1 million 1997*

Germany's geothermal research program is small in comparison with other government-sponsored energy research programs and in comparison with the geothermal programs of other countries such as the United States, Iceland, Japan, and Italy. Nonetheless, there is considerable potential for geothermal energy use in Germany. Technologies for the use of deep aquifer hydrothermal energy have attained feasibility and are being demonstrated in several thermal power plants.

Renewable Energy for Developing Nations *$7 million 1997*

BMBF and the Federal Ministry for Economic Cooperation and Development (BMZ), in partnership with other institutions, work closely with developing countries in the area of renewable energy. In support of these efforts, BMBF engages in scientific and technical cooperation, and technology demonstration aimed at bringing renewable technologies to the point of commercial viability in less developed countries. Between 1974 and 1994, Germany invested nearly $350 million, principally in the development of solar thermal power, photovoltaic and solar thermal water pumps, desalination, and solar ovens and dryers for deployment in developing countries. Future efforts of the BMBF will focus on both wind and solar technologies, through its ELDORADO Program. This program sponsors demonstrations and market conditioning efforts aimed at improving the feasibility of German technologies in developing countries by improving financial conditions and underwriting technological and economic risks associated with demonstration projects.

Waste to Energy[ix]

Waste to energy projects supplied only 0.5% of Germany's electricity in 1994—less than that of hydropower. This is attributable, in part, to the low conversion efficiency associated with the burning of solid waste. Nonetheless, several basic research projects and technology demonstrations aimed at improving the feasibility of waste to energy are in progress. Research aims to improve the conversion efficiency of waste-to-energy technologies, which currently stands at 2.2-3MWh/ton and also focuses on the minimization of the potential environmental impacts associated with gaseous and solid wate products resulting from the burning of municipal waste for power generation.

Nuclear Energy

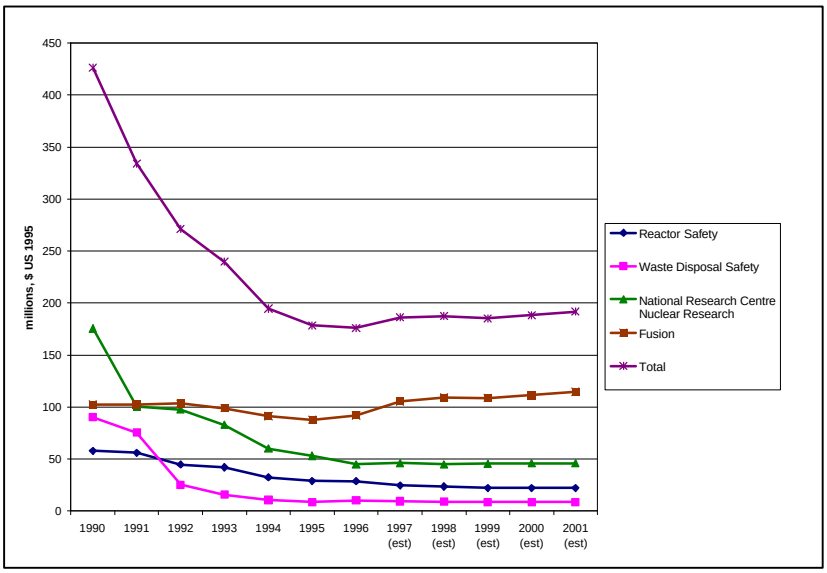
The German government has long considered nuclear energy an important part of the nation's energy strategy, which aims to secure economically and ecologically sound energy supply in the long-term. Over the past decade, however, popular and government support for nuclear energy has dropped off significantly, largely in response to public perceptions regarding the safety and environmental hazards associated with nuclear energy. Federal support for nuclear fission esearch has fallen by more than 90% since 1985. When the Social Democratic-Green Party coalition government took office in late 1998, it pledged a full phaseout of nuclear power in Germany over the course of an

unspecified period. Thus, the future of nuclear energy is now highly uncertain in Germany. Currently, some 30% of Germany's electricity and 10% of primary energy is nuclear generated. While in the past a large portion of government funding for nuclear energy R&D has been directed to the development of new reactor designs, a much smaller portion of R&D resources are devoted to this area of inquiry. The nuclear research program now focuses primarily on reactor safety, the development of components with inherent "fail safe" characteristics, and nuclear waste disposal. The government also funds a large thermonuclear fusion research effort, which has fared relatively well in recent years, remaining relatively constant at approximately $100 million annually throughout the 1990s.

Reactor Safety Research *$25 million 1997*

The most important goal of the reactor safety program is to establish a strong scientific and technological foundation for the assurance of safety in nuclear facilities and equipment. To this end, the program has always aimed for continuous improvement of safety equipment, and component materials and monitoring. Further research activities include development of models specifying and quantifying component conditions and understanding material properties and potential for failures; further development of the ATHLET model, which enables the realistic analysis of the condition of thermohydraulic equipment in light water reactors; and human factors research.

Figure 9. Actual and Planned German Government Nuclear R&D Expenditures 1990-2001



Waste Disposal Safety *$10 million 1997*

The secure long-term storage of nuclear wastes is a central element of Germany's nuclear research program. It also remains one of the most controversial issues of public discourse. Currently, the safest and most promising option for the disposal of Germany's nuclear wastes (approximately 500,000 m^3 of heavy metal-contaminated dust and fly ash, and some 3100 m^3 of radioactive wastes) is storage in deep geological structures such as Germany's salt formations. Unlike chemical waste disposal, for which states have responsibility, nuclear wastes are the responsibility of the federal government exclusively. Continuing research in this area includes the following activities: further development of measurement technologies, particularly methods for site characterization and program evaluation; advancement of understanding of physical-chemical processes as they relate to the transport of contaminants in the biosphere; further development of assessment processes for the determination of long-term safety options; further development of non-salt dome formations (especially granite) for waste storage; and monitoring of nuclear materials.

Radiation Safeguards[x]

The Federal Environment Ministry (BMU), under whose jurisdiction fall the federal laws concerning nuclear energy, radiation protection, and related research, sponsors a broad range of research activities in the area of radiation safeguards aimed at protecting the population from the harmful effects of ionizing radiation. BMU also sponsors non-radiation research, which has taken on greater significance in recent years. Research in this area addresses electromagnetic fields and optical radiation, particularly UV, infrared, and laser radiation. Ongoing research activities also include analyses of exposure to natural and man-made radiation sources; measurement technologies and dose measurement; somatic and genetic effects of radiation exposure; accident preparedness; radiation risks associated with the presence of radioactive materials and ionizing radiation; protection from radiation during handling and disposal of radioactive wastes; and radiation-related pathology (including diagnosis and treatment).

Nuclear Fusion *$105 million 1997*

The complexities associated with plasma physics and fusion technologies are exceptional, and thus, the government believes the development of a production-ready reactor is still decades away. Germany's fusion research activities are integrated with the European Union's fusion program, coordinated by EURATOM. Germany also participates in international research efforts with individual EU member states and with Switzerland. The Max Planck Institute for Plasma Physics, the National Research Center in Jülich, and the Nuclear Research Center in Karlsruhe all participate in plasma physics research and in other major research efforts sponsored by the German government.

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[i] BMBF, 1998. *Faktenbericht 1998*, pp. 378-379. Data presented here for 1997 and 1998 are estimates.
[ii] BMBF, 1993. *Bundesbericht Forschung 1993*; BMBF 1996. *Bundesbericht Forschung 1996*.
[iii] BMBF, 1996. "Jahresbericht der Bundesregierung 1996: Spitzen- und Schlüsseltechnologien: Neues Energieforschungsprogramm" http://www.bmbf.de/vrbmbf/inhalt.htm
[iv] BMBF, 1996. *Bundesbericht Forschung 1996*, p. 160. It is also important to note, however, that the federal budget for fossil energy R&D declined by 50% (to $23 million) between 1992 and 1996, and that funding for programs supporting this focus area (e.g., clean coal technology) has been particularly hard hit.

[v] BMBF, 1996. *Bundesbericht Forschung 1996*, p. 161.
[vi] The descriptions of German technology programs provided here are from BMBF, *4. Programm Energieforschung und Energietechnologien* (Bonn, 1996), and BMBF, *Bundesbericht Forschung 1996* (Bonn, 1997). All 1997 budget data included in this section represent planned government expenditures.
[vii] BMBF, 1998. *Faktenbericht 1998*, p. 106.
[viii] Includes research activities of the Federal Research Ministry (BMBF) and the Federal Agricultural Ministry (BML).
[ix] Funding data not available.
[x] Funding data not available. BMBF and the Federal Environment Ministry (BMU) both sponsor R&D activities in this area.