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Energy R&D in Germany

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**Pacific Northwest National Laboratory
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ABSTRACT: Germany's total national (i.e., combined public and private sector) funding for R&D stood at $42 billion in 1997. The private sector accounted for nearly 62% ($24 billion) of the total, while the public sector accounted for approximately 38%. Since the late 1970s, when the public and private sectors each funded roughly half of Germany's R&D, the private sector has steadily assumed a larger and larger role as the dominant supporter of R&D activity, while overall government funding has remained essentially flat for much of the past two decades. In addition to declining relative to private R&D expenditures, public R&D expenditures in Germany declined by 4% in real terms between 1991 and 1997, to approximately $15 billion. The reduction in R&D investments in the public sector can be attributed in large part to the financial challenges associated with German reunification and related shifts in social priorities including efforts to address high unemployment and to rebuild basic infrastructure in the eastern states. R&D expenditures have also declined as a percentage of the total public budget, from a peak of 3.4% in 1985 to 2.7% in 1996.

Energy R&D has been the hardest hit of all major socioeconomic areas of R&D expenditure funded by the German government. Between 1981 and 1997, public energy R&D fell from approximately $1.6 billion to $400 million--a 75% real decline. The $850 million reduction in Germany's fission R&D budget (which constituted two-thirds of government R&D investment in 1985) explains some 90% of the funding decline. Negative public perceptions regarding the safety and environmental impacts of nuclear energy have reduced nuclear power's viability as a long-term energy option for Germany. Discussions of a complete nuclear phaseout are now under way. At the same time, the German government has slashed its investments in fossil energy R&D by more than 90%. While energy efficiency and renewable energy technologies have fared relatively well in comparison with other energy technology areas, government support for all areas of energy R&D has declined in absolute terms since 1990. Remaining public and private sector energy R&D investments focus increasingly technology demonstration and commercialization efforts with relatively short time horizons.

Germany

Population: 82,079,454 (1998 est.)
GDP: $1.74 trillion.[i] (1997 est.)

National R&D Effort 1997

- $42 billion.[1]
- Gross domestic expenditure on R&D as a percentage of GDP 1997: 2.4%.[2]
- Percentage of R&D expenditure financed by:
  - -Public Sector: 38.4%
  - -Private Sector: 61.3%
  - -Non-Profit Sector: 0.3%
- Federal energy R&D expenditure 1997: $394 million.[ii]
- Private sector energy R&D expenditure 1995: $168 million[iii]

Chapter Overview

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[i]BMBF (Federal Research Ministry), *Basic and Structural Data, 1996/97*, p. 198. All figures shown are based on purchasing power parity calculations made using currency deflators published by the Organization for Economic Cooperation and Development (OECD). See OECD, Statistics Directorate, *National Accounts 1960-1996: Main Aggregates Volume 1* (Paris: OECD, 1998).
[ii] BMBF 1998. *Faktenbericht 1998 zum Bundesbericht Forschung*, p. 379. This figure includes federal government expenditures only.
[iii] Stifterverband fur die Deutsche Wissenschaft, Wissenschaftstatistik, *Forschung und Entwicklung in der Wirtschaft 1995-1997* (Essen: Wissenschaftsstatistik GmbH, 1997), p. 36. This figure includes private R&D expenditures in both the energy and water supply industries (industrial classification category 10) and combines the expenditures of individual firms as well as industry research consortia.

Summary of Analytical Findings

Germany's total national funding for R&D stood at $42 billion in 1997. The private sector accounted for nearly 62% ($24 billion) of the total, while the public sector accounted for approximately 38%. Since the late 1970s, when the public and private sectors each funded roughly half of Germany's R&D, the private sector has steadily assumed a larger and larger role as the dominant supporter of R&D activity, while overall government funding has remained essentially flat for much of the past two decades.

Overall public R&D expenditures in Germany declined by 4% in real terms between 1991 and 1997, to approximately $15 billion. The reduction in R&D investments in the public sector can be attributed in large part to the financial challenges associated with German reunification and related shifts in social priorities (e.g., high unemployment and basic infrastructure needs in the eastern states). R&D expenditures have also declined as a percentage of the total public budget, from a peak of 3.4% in 1985 to 2.7% in 1996.

Private R&D investments grew by 5% between 1995 and 1997. Prior to 1995 private sector R&D expenditures had declined throughout the 1990s attributable in part to weak economic growth in Germany and from relatively unfavorable international terms of trade. Germany's private sector R&D is concentrated in industries that generate a major portion of their revenues through exports and that are particularly vulnerable to exchange rate fluctuations; the high foreign value of the Deutschmark has put downward pressure on foreign sales and further intensified the competitive pressures on industry's R&D projects.

Energy R&D has been the hardest hit of all major socioeconomic areas of R&D expenditure funded by the German government. Between 1981 and 1997, public energy R&D fell from approximately $1.6 billion to $400 million--a 75% real decline. The $850 million reduction in Germany's fission R&D budget (which constituted two-thirds of government R&D investment in 1985) explains some 90% of the funding decline. Negative public perceptions regarding the safety and environmental impacts of nuclear energy, especially following the 1987 Chernobyl crisis, reduced nuclear power's viability as a long-term energy option for Germany.

Government-sponsored fossil energy programs have declined sharply--by 95%--from $316 million in 1981 to $20 million in 1997. Government support for fossil energy R&D now focuses primarily on the development of advanced energy systems such as fuel cells, advanced combustion research, and the development of vehicles powered by natural gas, methanol and other alternative fuels. Germany relies increasingly on natural gas, for environmental and economic reasons, and no longer funds large clean coal or other fossil energy programs.

Germany's public energy R&D investment portfolio has intensified its focus in the areas of renewable energy and energy efficiency. R&D in these areas, which accounted for 14% of the energy budget in 1981, now account for approximately 36% of public energy R&D (approximately $140 million in 1998).

More so than in most other industrialized countries, global climate change has become a major factor in German energy policy. Under the Kyoto Protocol and the European Union's Community Strategy on Climate Change, Germany has committed itself to a 21% reduction in greenhouse gas emissions from 1990 levels by 2008-2012. The reduction of greenhouse gas emissions and the transition to low- and no-carbon energy technologies is now a major stated policy goal. This major shift in policy goals highlights a dislocation between Germany's current energy policy and its related R&D expenditures, since public support for energy R&D has declined throughout the 1990s.

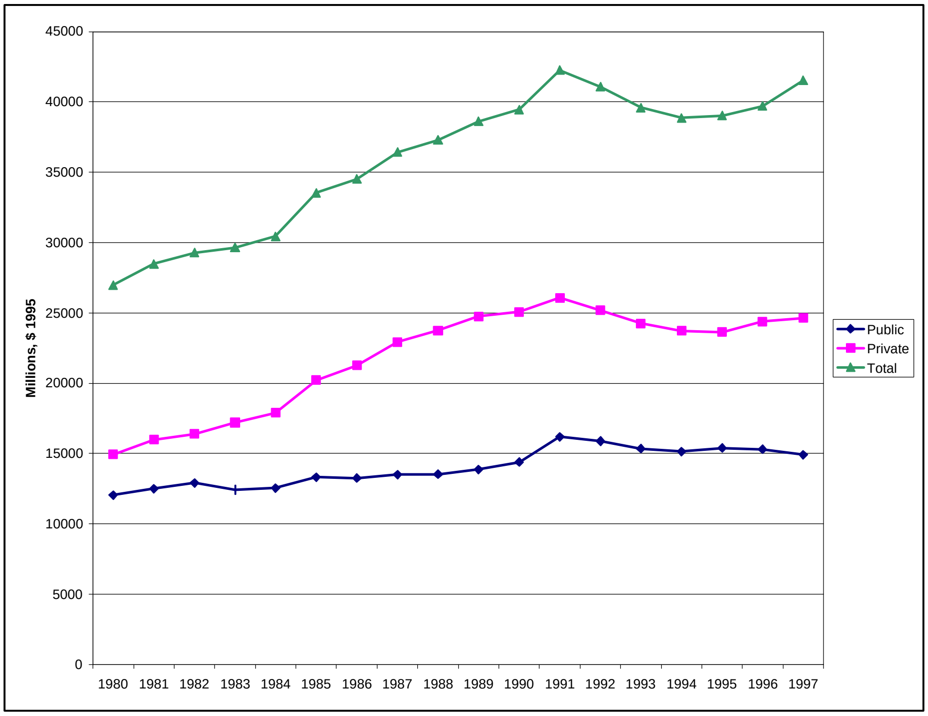
Shortly after taking office in October 1998, Germany's Social Democratic-Green Party coalition government announced controversial plans to phase out all nuclear power plants in Germany and to raise taxes further on electricity and fossil fuels. Since nuclear power currently generates more than 30% of the country's electricity, attempts to achieve this goal rapidly will intensify the challenge of reducing carbon emissions, which the government has also listed among its policy priorities.

The development and export of new low-carbon or no-carbon energy technologies to mitigate climate change and other environmental impacts of energy use have become important dimensions of Germany's economic and trade policy. The German government and industry are working together to set the international standards for new energy and environmental technologies, a strategy that, if effective, could help position Germany to dominate key technology markets in the future.

National Science and Technology Effort and Funding Goals

Germany's public and private sector R&D expenditures peaked in real terms in 1991. Since reunification, Germany's public R&D expenditures have declined both as a percentage of GDP and in real terms in subsequent years.[3] From its peak of 3.5% of the public budget in 1985, Germany's public R&D expenditures fell steadily over the ensuing decade, reaching a 30-year low of 2.6% in 1994.[4] Similarly, private sector R&D declined by 6% in real terms between 1991 and 1997, after more than a decade of steady growth. In 1997, total national R&D spending in Germany was approximately $42 billion. The public and private sectors contributed $15 billion and $25 billion to the total, respectively. The non-profit sector accounted for the remainder of about $2 billion.

Figure 1. Germany R&D Expenditures by Funding Sector 1980-1997[5]

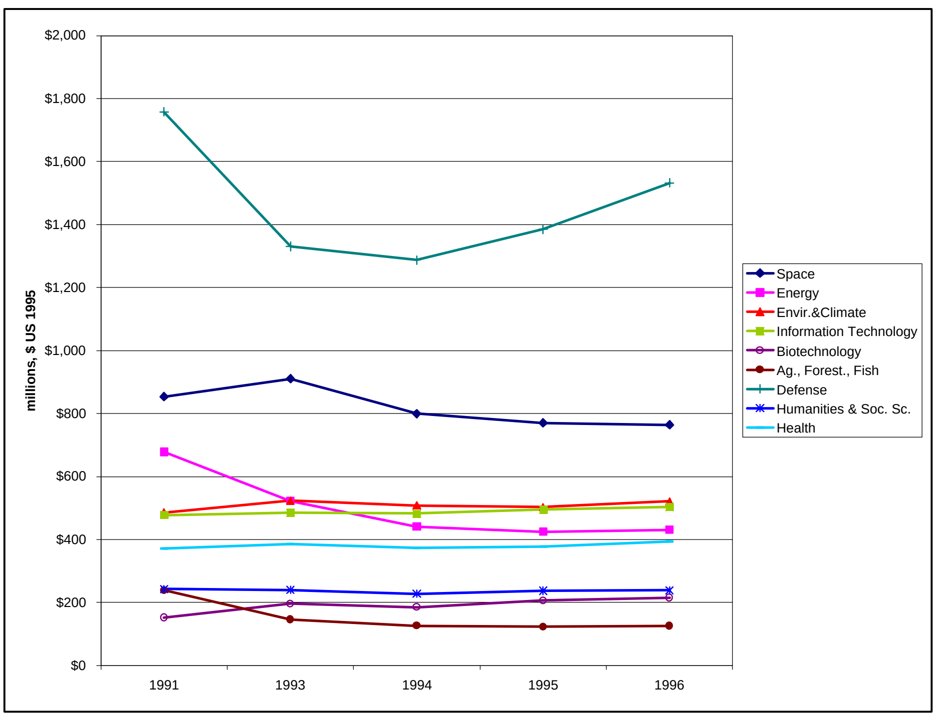


A few key factors help to account for the observed declines in private sector research sponsorship. According the Federal Research Ministry (BMBF), in many cases innovation has been dampened by the high risks associated with the development of new high technology products coupled with a relative scarcity of risk capital, which has had a particular impact on small and medium-sized enterprises.[6] Also, since Germany's technology-related industries generate a major portion of their revenues through exports, they are particularly vulnerable to exchange rate fluctuations; the high foreign value of the deutschmark that persisted throughout the first half of the 1990s, for example, put downward pressure on foreign sales of technology products and further intensified the competitive pressures on industry's R&D projects. Many companies, particularly small and medium-sized enterprises, have found it prohibitively expensive to make financial commitments to innovative projects with longer amortization periods and higher risks.[7]

Trends in government-sponsored R&D have been influenced by several major developments in Germany's regulatory framework and political economy. The progress made to date in integrating the eastern states into the larger German economy and society has come at an annual cost to the west of approximately $100 billion; major federal expenditures for German reintegration are expected to remain necessary for several years to come.[8] The size of these investments in the east has forced the government to reduce substantially its spending on other priorities. Federally sponsored R&D programs have also felt the the effects of the government's diversion of resources to the east as well as the impact of Germany's slow economic growth, high unemployment, and generally tighter government revenues during the 1990s.

Germany's public sector energy R&D support, discussed in greater detail below, has experienced the sharpest declines of any socioeconomic area--71% between 1985 and 1996 (see Figure 2). This trend is attributable in large part to funding cuts in Germany's nuclear fission programs, particularly those aimed at the development of new reactor technologies (see Figure 3).

Figure 2. Federal R&D Expenditures in Selected Areas, 1981-1996[9]



One of the growth areas in Germany's public R&D spending in the 1990s has been defense. Defense R&D spending rose by more than 15% between 1994-1996 to a level of $1.5 billion—18% of the total government R&D budget. The German government has augmented its defense R&D budget in an effort to update weapons and information systems in the interest of readiness and defense integration with the European Union. According to the Federal Ministry of Defense, these increased expenditures are "unavoidable," given the changing nature of military missions in the post-Cold War era, particularly Germany's need to be a full and equal partner in its alliance structures (e.g., NATO and WEU) and in major joint military R&D projects, such as the Eurofighter 2000. Over 70% of Germany's major defense R&D projects are now carried out in the context of international partnerships. Germany also views its defense R&D investments and participation in alliance activities as contributing to the further development of a common European defense identity and, thus, to European integration. The level of Germany's defense R&D expenditures is expected to decline over the next few fiscal years in response to at least two key factors.[10] First, the overall scarcity of government resources makes the current level of defense R&D expenditures unsustainable. Moreover, considering the continually growing complexity of technology and R&D, Germany will pool its defense research resources with other European countries (mainly France) for the development of multinational defense R&D initiatives and, ultimately, the creation of an international armaments agency.[11]

Environmental and climate research has grown modestly in recent years, driven in part by growing efforts to improve scientific understanding of global change. Similarly, investments have grown in several applied environmental technology areas, including handling and recycling of municipal wastes, water and waste water treatment, and remediation of conventional defense wastes. R&D expenditures in this area are expected to increase by some $40 million in 1998 to reach a total of $500 million.[12]

Biotechnology has become a major R&D priority in Germany. The German government believes that biotechnology will be one of the most important scientific and technological fields over the course of the next century and a key to future economic growth. Considering the globalization of markets for high technology products, the government believes that it will be essential for Germany to build its biotechnology science and technology base in order to take advantage of the growing world market opportunities in this area. Its "Biotechnology 2000" program aims to augment the domestic science base and at the same time to promote and accelerate the commercialization of biotechnological innovations. The government has ranked this area among its top R&D priorities, stating that it is imperative that Germany maintain its position among the leading biotech nations into the future. Between 1994 and 1997, federal biotechnology R&D investment grew from $185 million to $216 million—a real increase of 15%.[13]

Information technology is also a priority research area for the German government. Federal support for information technology has grown slowly but steadily throughout the 1990s, by 5% between 1991 and 1996 to a level of $503 million. While the federal government supports a wide range of scientific and technological research in the information technology fields, including basic information science, artificial intelligence, photonics, and advanced computation, multimedia research has grown most rapidly of all in terms of federal funding. The government belives that multimedia, denoting the fusion of text, graphics, pictures, sound, and film via digital information technology platforms, will play an important role in the future success of service-based economies such as Germany's. The federal government nearly doubled its support in this area from $31 million to approximately $60 million between 1994 and 1996 to spur development of new potential applications and to build the domestic research.[14]

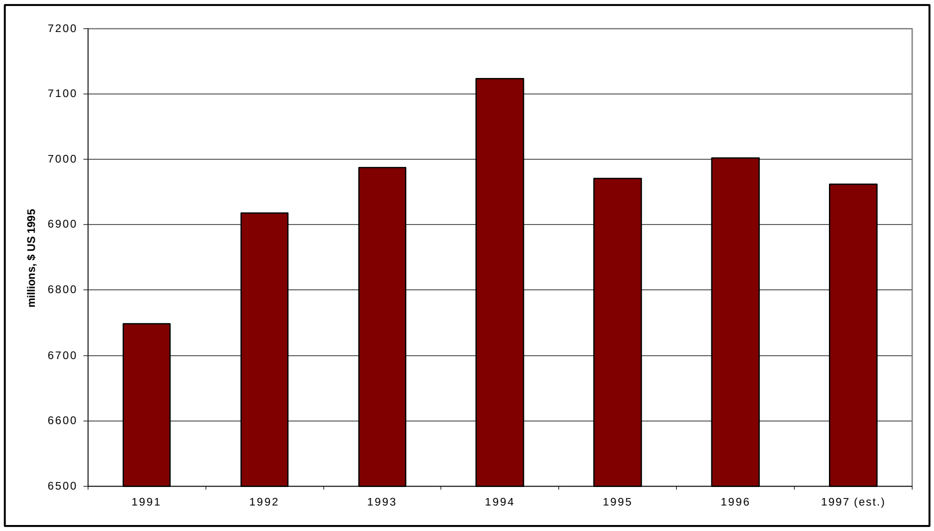
Science and technology play central roles in the achievement of several of the German government's priority policy objectives. One of the most important of these goals is the solidification of a reunified Germany and the reconstruction of the eastern German states. The rebuilding of the badly deteriorated research infrastructure in these states has been a cornerstone of the government's reunification efforts, since R&D-intensive industries are regarded as engines of Germany's future employment and economic growth, and social well-being. Between 1991 and 1994, the federal government invested some $5.2 billion in the eastern states for the construction of several new research institutes, the refurbishment of universities, and for R&D projects.[15] Eastern Germany now is home to many new research institutions, including 3 National Research Centers, 18 Max Planck institutes, 9 Fraunhofer Society institutes, and 25 Blue List institutes.[iv]

The Schroeder government is addressing the need to strengthen Germany's university-based basic science capabilities and to design new mechanisms and incentives promoting collaboration between university researchers and the private sector. Germany's universities and other institutions of higher education, which performed an estimated $7 billion worth of research in 1997, are a major element of the country's research infrastructure. Most funding for the higher education sector comes in the form of institutional block grants from state-level government. Since government support for university research has dwindled, as Figure 3 shows, the federal government believes that the creation of more collaborative ventures involving universities and firms within Germany and across international borders will be essential to the future health of Germany's university-based research capabilities. Thus, the promotion of private sector-university collaboration has become an important element of Germany's science policy.[16]

In one of its earliest statements on science and technology policy, the Schroeder government has recognized the importance of investment stability for a healthy R&D enterprise and for the health of the economy. Addressing the volatility that has recently characterized the R&D investment climate, which the government believes has compromised Germany's position as a world leader in important research areas, will be a policy priority in the new Administration.[17] The Schroeder government has taken an important first step toward achieving this goal by securing a substantial increase in the 1999 budget of the Federal Research Ministry (BMBF).

[iv] See Appendix A for a description of the missions of each of these institutions in the German research infrastructure.

Figure 3. Higher Education Expenditures on R&D, 1991-1997[18]



The BMBF's 1999 budget will rise by some $424 million over that of the previous year, bringing its total budget to just over $7 billion. More than $300 million of the new funding will be directed to the university sector for the construction of new research facilities and to provide support for scientific education. Approximately $60 million in new funding will be used to sponsor research projects in high priority areas, including biotechnology, information technology, and transportation research.[19]

Energy Overview and Energy Policy[20]

Germany is the world's fifth largest energy consumer--14.4 quadrillion Btu, or quads, in 1996. Germany consumes about 2.9 million barrels per day (bbl/d) of oil, nearly all of which it imports. Germany consumed 3.7 Tcf of gas in 1996, around 80% of which it imported. Germany has coal reserves of 74.2 billion short tons (bst), of which 36% is hard coal (anthracite and bituminous), while 64% is soft coal (lignite and subbituminous). Currently Germany ranks fourth worldwide in installed nuclear capacity, behind the United States, France, and Japan. Nuclear power generates some 30% of Germany's electricity supply. The contribution of renewable energy to Germany's fuel mix is growing steadily. This is due, in part, to the fact that German utilities are now obligated to pay independent power producers (IPPs) a minimum price of 90% of their average electricity rate for wind and photovoltaic energy (about 10 cents per kWh), and 70% for energy from water, biomass, or biogas. As of early 1998, the total capacity of wind power reportedly reached 2 GW, making Germany the largest producer of wind energy in the world.

Figure 4: Germany's Total Energy Consumption 1996 (14.4 Quads)

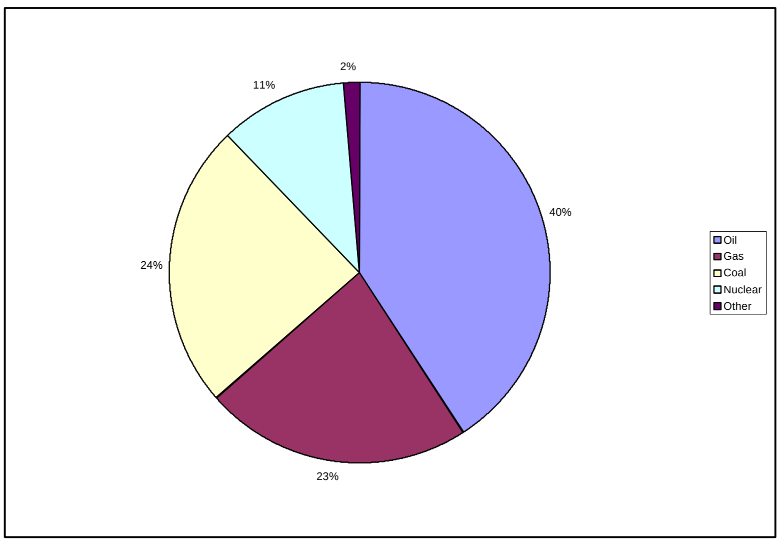


Table 1. Germany: Energy Overview 1996

Dependence on Energy Imports: 63%	Energy-Related Carbon Emissions: 870 million metric tons
Energy Consumption per Capita: 176.3 million Btu	Carbon Emissions per $1000 GDP: 0.16 metric tons
Energy Consumption per $1 GDP: 9500 Btu	Carbon Emissions per Capita: 2.9 metric tons
"Kyoto Commitment": 21% reduction in greenhouse gas emissions from 1990 levels by 2008-2012	Energy Use Per Unit GDP 1995: 4.7 MJ.[21]

Germany's energy policy has two overarching goals: (1) to forge a consensus on future energy security and energy use, particularly with regard to the roles of coal and nuclear energy, energy conservation, and the more intensive use of renewable energy sources; and (2) to ensure environmentally benign energy supply and use. There are also four major issues, discussed below, around which the energy policy debate in Germany now revolves.

Climate Change. One of the German government's main efforts in the 1990s has been the development and application of a comprehensive strategy for the protection of the global climate. Germany has been a leading proponent of international political action to mitigate global climate change and a strong supporter of international treaties such as the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Under the terms of the Kyoto Protocol, the European Union has committed itself in principle to a 7% reduction in greenhouse gas emissions from 1990 levels by 2008-2012. Within the European Union, however, the emissions reduction obligations of individual countries will differ significantly, as specified in the Community Strategy on Climate Change. Germany has committed itself to a 21% greenhouse gas emissions reduction, while other countries, including France, will have no reduction obligations.[22] The German government intends to achieve this target through a combination of policy measures including carbon taxes, renewable energy portfolio standards, and legislation such as the Electric Feed Law. This law requires German utilities to purchase renewably generated electricity from independent power producers at a minimum price of 90% of the average electric rate for wind and solar photovoltaic energy, and at 70% of the average rate for electricity generated by water, biomass, and biogas.[23]

The German government has also been working to secure the participation of German industry in climate change mitigation efforts. For example, in 1996, after three years of intensive negotiations, the government reached agreement with industry regarding voluntary emissions reduction commitments. During that time, industry's position on voluntary commitments gradually evolved from resistance to acceptance of voluntary carbon emissions reductions. Industry's attitude changed as it became clear that its failure to adopt for itself responsibility for emissions reductions would result in the imposition of new regulations that would allow much less flexibility in achieving reductions. According to industry estimates, voluntary measures will produce an absolute reduction of 170 million tons. An independent monitoring agency has been tasked with oversight reponsibility for the program.[24]

Germany has demonstrated sincere commitment to lead in addressing the climate change problem and to act unilaterally on the issue. The limits of this commitment will be tested in upcoming years, however, as rising taxes on fossil fuels coincide with efforts to phase out Germany's nuclear power capacity (discussed below).

Energy Security. Security of Germany's energy supply is also an important policy objective, given the country's heavy dependence on energy imports (approximately 96% and 80% for oil and natural gas, respectively). Germany relies for its energy security on cooperative arrangements with the members of the European Union, the International

Energy Agency, and the countries of Eastern Europe and the former Soviet Union. For example, Germany is participating in the European Union's efforts to create trans-European energy networks integrating the gas and electricity systems of all EU Member States and forging network linkages with non-EU countries, such as Russia and Algeria, as well.[25]

Hard coal and lignite will continue to help safeguard Germany's energy supply for the foreseeable future, although the contribution of domestic hard coal will become much smaller in the future. Rising domestic coal production costs make it increasingly difficult for Germany's coal producers to compete with cheaper foreign suppliers. Nevertheless, the federal government and the governments of Germany's two major coal states, North Rhine-Westphalia and Saarland, still provide large subsidies for coal mining in order to preserve jobs in the domestic coal industry.

The German government's energy security policy extends beyond measures aimed at ensuring reliable supplies of fossil fuels. For example, the 1991 Energy Plan focuses on several major developments affecting Germany's energy sector in the aftermath of reunification. The Energy Plan addresses the energy security implications of changes in the international political context, such as European integration, the threat of global climate change, and the ongoing political and economic transformations in Central and Eastern Europe. In addition, it embodies important policy shifts, favoring the increasing use of market-based mechanisms rather than government intervention for the management of the economy and as an instrument of energy security. At the same time, the plan calls for increasingly strict safety and environmental legislation, which has resulted in the closure of several nuclear power plants in the former East German states.

The Future of Nuclear Power. Nuclear energy has played a central role in German energy policy over the past three decades. However, the extent to which nuclear energy will continue to enjoy its central role in German energy is an open question. One of the first actions of Germany's Social Democratic Party-Green Party coalition government in October 1998 was the declaration of its intent to phase out all of Germany's nuclear power plants, which currently supply over 30% of the nation's electricity. The timeline for these plant closures is, as yet, undetermined, with estimates ranging from one to twenty years.

In conjunction with its proposed elimination of nuclear power in Germany, the new government has proposed to increase taxes on gasoline, heating oil, and electricity as a means of encouraging conservation and use of renewable energy, and as a means of raising revenues to finance social security programs.[26] The extent to which these policy measures are feasible remains to be seen. Since nuclear power is Germany's major non-carbon-emitting energy source, its elimination would require its replacement by a combination of energy conservation, and energy from other sources—most likely from fossil fuels in the short to mid-term. The rapid elimination of nuclear power would make it extremely unlikely that Germany would be able to meet its international greenhouse gas reduction commitments, while the levying of new taxes on fossil fuels would further constrain German industry and consumers in their energy options.[27] However, it is also important to note that the current nuclear phase out plan applies only to nuclear power generated in Germany. Imports of nuclear-generated electricity from other parts of Europe, namely France, would not be restricted or penalized.

Utility Restructuring. Another major development in Germany's energy policy is movement toward the deregulation of the energy industries, particularly electric and gas utilities. Energy deregulation is closely related to other economic and political goals, such as the enhancement of international economic competitiveness, particularly for energy-intensive export industries, and the advancement of European integration through the creation of trans-European energy networks. Energy integration among the countries of the European Union is an important element of the development of a common EU market for all goods and services. From a legal standpoint, energy integration is mandated by the EC Treaty, which defines the internal market as an "area without internal frontiers in which the free movement of goods and persons, services, and capital is ensured." [28] Deregulation will help to reduce barriers to energy transactions within the EU and is intended to result in lower energy prices for European consumers and industry—most of whom pay higher premiums for energy than those of other regions. Trans-European energy networks will also contribute to Germany's and Europe's energy security by enhancing overall system flexibility.[29]

Competition in Germany's energy industries is very limited currently, although proposals are now being considered for the revision of the legal and regulatory frameworks to allow third-party access. In the electric utility industry, for example, nine supra-regional monopolies control 80% of generation and nearly all transmission. Sixty regulated regional companies produce or distribute electricity over about two-thirds of the country; 40% of distribution is controlled by the "big nine" utilities, while another 850 companies, including many small-scale, local electricity cooperatives, are involved in distribution alone.[30] The highly-fractured nature of the German electricity market indicates that it could take several years for full retail competition to be achieved nationwide. Legislation passed in 1998, however, opened approximately 25% of electricity generation and transmission market to competition as of February 1999.[31]

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[32]

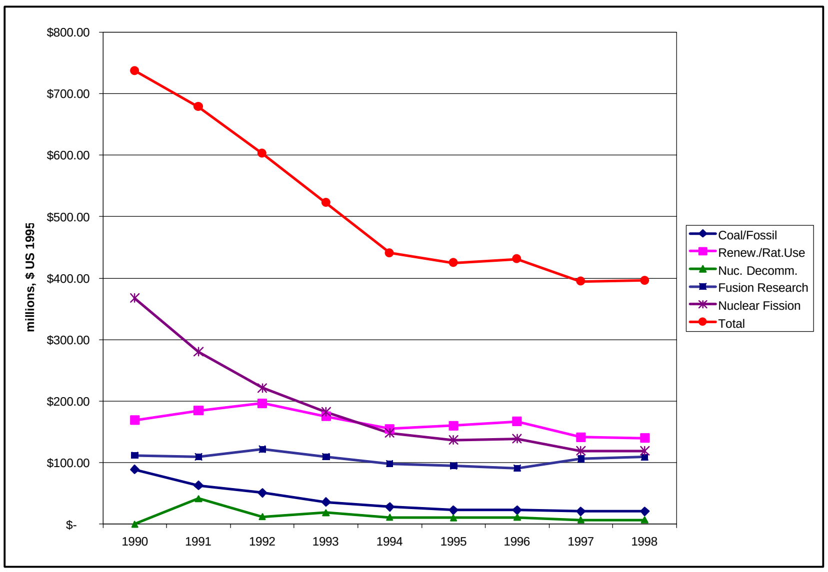
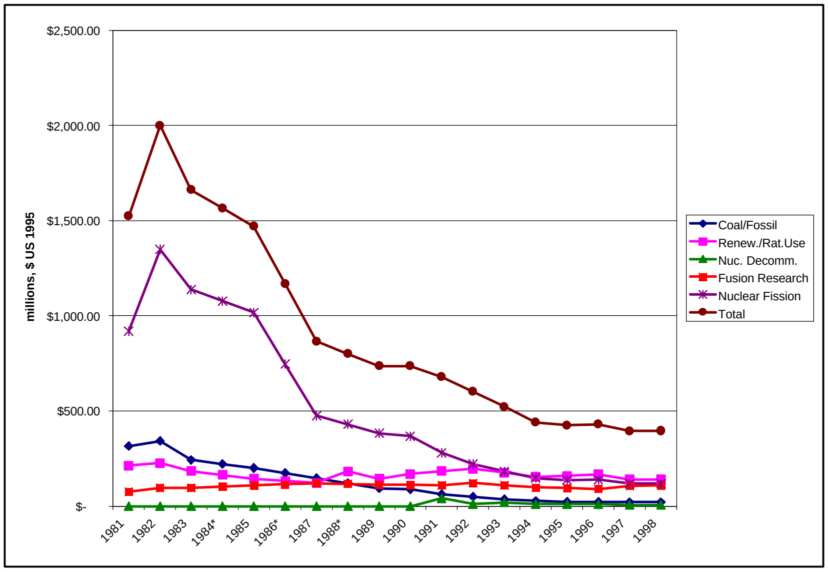


Figure 6. Federal Energy R&D Expenditures 1981-1998[33v]



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[34]:

- 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.[35]
- 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.

[v] 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.[36]

Key Technology Areas[37]

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*

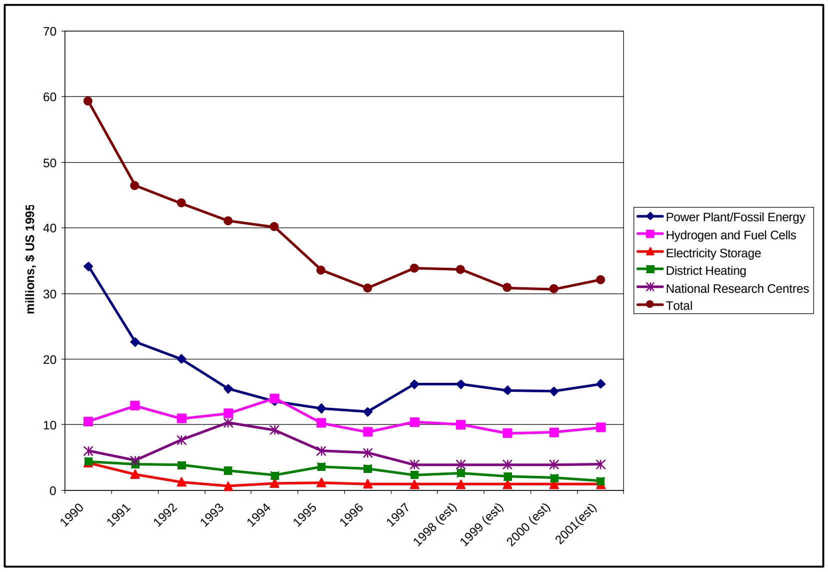
Research in this area has been a major part of previous government-sponsored energy research programs; consequently, the government believes a broad scientific and technical base exists as a foundation for future developments. Thus, funding for industrial efficiency has declined slightly in recent years. 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[vi]

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.

[vi] 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.

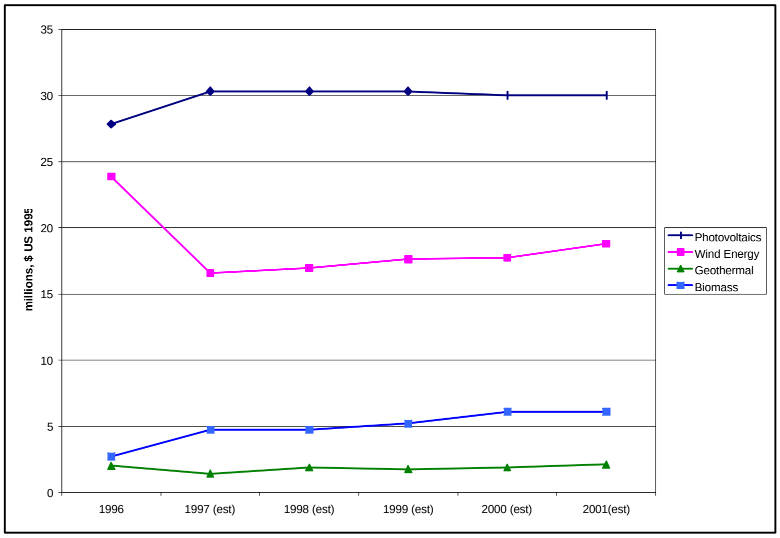
Renewable Energy

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.[38] 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[39] *$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[40]

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.

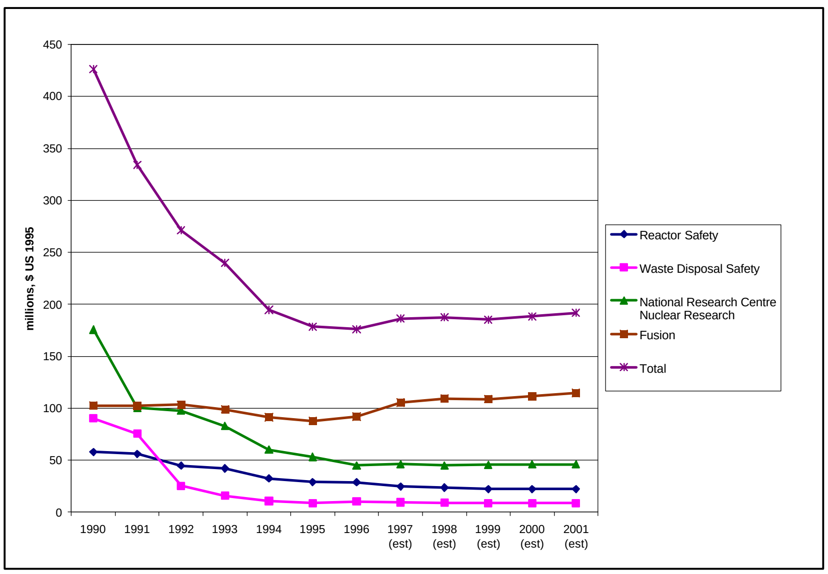
Nuclear Energy

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[41]

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.

Appendix A. Germany's Public R&D Infrastructure

Germany's public research infrastructure is large, broadly based, and decentralized; research sponsorship and policy-making involve government agencies and independent advisory bodies at both the federal and state levels. Major research performers include the German university system and a large network of independent research institutes. Brief descriptions of Germany's major research sponsors and performers, and advisory bodies are provided below.

- Federal Government Agencies are major sponsors of non-university based R&D. The largest federal supporters of R&D are the Ministry of Education, Science, Research and Technology (BMBF), the Ministry of Defense, and the Ministry of Economics. In 1995, federal authorizations for science, research, and development totaled some $9.8 billion.

- Max Planck Gesellschaft (MPG) is the most important organization for basic research outside of the German university system. MPG consists of more than 60 institutes and special facilities; it receives its funding from both the federal government (50%) and the state governments (50%). MPG's 1996 public funding was $717.5 million.

- Fraunhofer Gesellschaft (FhG), with over 50 research institutions, is Germany's principal performer of applied research and development. FhG's goal is to promote the deployment of new technologies in the nation's economy and thereby to strengthen Germany's international economic competitiveness. FhG institutes receive institutional funding from the federal and state governments, but rely on contracts with industry clients for approximately 70% of their annual revenues. The FhG institutions' 1996 public funding totaled $239 million.

- National Research Centers are 16 major institutions that collectively form the Hermann von Helmholtz-Gesellschaft (HFG). The Centers—Germany's national laboratories—conduct R&D requiring interdisciplinary cooperation and concentration of personnel, finances, and unique, specialized scientific equipment. The institutions work closely with universities, independent research institutes, and private sector firms from Germany and abroad. Each of the sixteen research centers is funded by the federal government (90%) and by its host state (10%). The Centers' 1996 public funding was $1.43 billion.

- Blue List Institutions (BLE) are independent research institutions and facilities with specialized research functions that have broad regional or national policy significance. Currently there are 83 BLEs; funding is provided by the federal government (50%) and state governments (50%). The BLEs' 1996 public funding was $621 million.

- German Research Society (DFG) DFG is the central public funding organization for academic research in Germany. DFG is comparable in its role to the U.S. National Science Foundation. DFG's mandate is to serve science and the arts in all fields by supporting research projects carried out in universities and public research institutions in Germany, to promote cooperation between scientists, and to forge links between German academic science and industry and with partners in foreign countries. In carrying out its mandate, DFG gives special attention to the education and support of young scientists and scholars. The DFG's 1996 public funding, which is provided by both the federal and state governments, was $973 million.[42]

- Academies are research institutions coordinated by the German Conference of Scientific Academies. The Institutes' research focuses almost exclusively on the humanities. Projects sponsored by the Institutes typically are of scope and duration that exceed the abilities of individual researchers and therefore cannot be conducted directly in a university setting. There are currently approximately 150 Academy Institutes, funded jointly by the federal government (50%) and state governments (50%). The Institutes' 1996 public funding was $33.5 million.

- The Science Council is an autonomous body made up of high-ranking representatives of the scientific community and government agencies. The Council plays an advisory role, assisting the federal and state governments in the formulation of science policy. The Council does not sponsor or perform R&D.

- State Governments (Länder) have primary responsibility for the German educational system. The Lander are the primary funders of university-based research and also formulate state-level R&D policy. In 1994, the federal states' R&D expenditures totaled $8.3 billion.[43]

- Universities (including independent technical colleges) are the largest research performers in Germany. While the majority of funding for university research comes from the federal states, the federal government (particularly the BMBF and German Research Society) and private sector are also major sponsors. Some additional funding comes from Germany's non-profit sector and from abroad. In 1995, funding for university research totaled $6.9 billion.[44]

- Industry is also a major sponsor of R&D in Germany. While public (state and federal) government sponsorship accounts for approximately 40% of the R&D budget, the private sector is now Germany's largest supporter of R&D, accounting for some 60%.

Structural Data 1995/96, p. 142-143.
[2] BMBF, 1996. *Basic and Structural Data 1996/97*, p. 143. Includes public, private, and non-profit sectors'
[2] BMBF (Bundesministerium für Bildung, Wissenschaft, Forschung, und Technologie), 1996. *Basic and* R&D expenditures.
[33] BMBF, *Basic and Structural Data 1996/97* http://www.bmbf.de/deutsch/zukunft/index.htm96/97, pp. 143-144.
[4] International Energy Agency, 1996. *IEA Energy Technology R&D Statistics 1974-1995*, pp. 89-93.
[5] BMBF, 1996. *Basic and Structural Data 1996/97*, p.143.
[6] BMBF, 1996. *Bundesbericht Forschung 1996*, p. 17.
[7] BMBF, 1996. *Bundesbericht Forschung 1996*, p. 17.
[8] U.S. Department of Energy/Energy Information Administration, www.eia.doe.gov/emeu/cabs/germany.html
[9] BMBF, 1996. *Bundesbericht Forschung 1996.*
[10]Deutsche Bundeswehr, "Sicherheitspolitische Grundlagen," http://www.bundeswehr.de/sicherheitspolitik/grundlagen/security-policy/I-5.htm; BMBF, *Faktenbericht 1998*, p. 166.
[11] BMBF, 1998. *Faktenbericht 1998*, p. 166.
[12] BMBF, 1998. *Faktenbericht 1998*, pp. 109-113.
[13] BMBF, 1998. *Faktenbericht 1998*, pp. 127.
[14] BMBF, 1998. *Faktenbericht 1998*, pp. 125.
[15] National Science Foundation, "How Is Science Faring in Germany's New Lands?," NSF/Europe Report No. 97 (February 1998), http://www.amb-usa.fr/nsf/nsf97.htm
[16] Edelgard Buhlmahn, Federal Minister for Education and Technology, Speech before the German Bundestag November 12, 1998, http://www.bmbf.de/deutsch/veroeff/presse/pm98/pm131198.htm
[17] Edelgard Buhlmahn, Federal Minister for Education and Technology, Speech before the German Bundestag November 12, 1998, http://www.bmbf.de/deutsch/veroeff/presse/pm98/pm131198.htm
[18] BMBF, 1998. *Faktenbericht 1998*, p. 44.
[19] "Haushalt `99: Bundesregierung Setzt Deutliche Priorität bei Bildung und Forschung: Haushaltsmittel Werden um Rund 904 Millionen Mark Erhöht, http://www.bmbf.de/deutsch/zukunft/index.htm
[20] Information in this section is from the U.S. Department of Energy, Energy Information Administration, "Country Analysis Brief: Germany," May 1998, http://www.eia.doe.gov/emeu/cabs/germany.html
[21] Calculation based on energy use per DM 1000 (real, 1995) economic output. [21] Bundesministerium fur Wirtschaft, 1998. *Energie Daten '97/'98*, p. 24.
[22] European Commission, "Energy for the Future: Renewable Sources of Energy," Green Paper for a Community Strategy COM (96)576, pp. 7-9.
[23] U.S. Department of Energy, Energy Information Administration, "Country Analysis Brief: Germany," May 1998 http://www.eia.doe.gov/emeu/cabs/germany.html
[24] 4. Bericht des Arbeitskreis I, Energieversorgung der Interministeriellen Arbeitsgruppe CO2 Reduktion, "Klimaschutz und Energiepolitik," Dokumentation Nr. 445, 1997, pp. 17-19.
[25] European Commission, Directorate-General for Energy (DG XVII), "Trans-European Energy Networks: Policy and Actions of the European Community," September 1997.
[26] "German Tax Reform Will Increase Energy Taxes," 23 October 1998, Price Waterhouse Coopers Tax News Network http://www.taxnews.com/tnn_public/
[27] See, for example, William Drodziak, "New German Cabinet Signals a Left Turn: Taxes, Social Policies to Be Revamped," *Washington Post* 20 October 1998, p. A. 15; Roger Cohen, "In Inaugural Speech, Schroeder Stresses Jobs and Environment," *New York Times* 11 November 1998.
[28] Gunther Rexrodt, "Energy Policy in the European Union," *Energy in Europe* No. 24 (15 September 1997) http://europa.eu.int/en/comm/dg17/24rex_en.htm
[29] European Commission, Directorate General for Energy (DG XVII), *Trans-European Energy Networks: Policy and Actions of the European Community*, September 1997.
[30] A.M. Klom, "Electricity Deregulation in the European Union," *Energy in Europe* No. 24 (15 September 1997) http://europa.eu.int/en/comm/dg17/24rex_en.htm

[31] See: Heimfrid Wolff, “Grenzen und Chancen einer dauerhaften und durchhaltbaren Entwicklung im Energiesektor (Kurzfassung),” im Auftrag des Bundesministeriums fur Wirtschaft, Bonn, November 1997 http://www.bmwi.de/

[32] BMBF, 1998. *Faktenbericht 1998*, pp. 378-379. Data presented here for 1997 and 1998 are estimates.

[33] BMBF, 1993. *Bundesbericht Forschung 1993*; BMBF 1996. *Bundesbericht Forschung 1996*.

[34] BMBF, 1996. “Jahresbericht der Bundesregierung 1996: Spitzen- und Schlüsseltechnologien: Neues Energieforschungsprogramm” http://www.bmbf.de/vrbmbf/inhalt.htm

[35] 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.

[36] BMBF, 1996. *Bundesbericht Forschung 1996*, p. 161.

[37] 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.

[38] BMBF, 1998. *Faktenbericht 1998*, p. 106.

[39] Includes research activities of the Federal Research Ministry (BMBF) and the Federal Agricultural Ministry (BML).

[40] Funding data not available.

[41] Funding data not available. BMBF and the Federal Environment Ministry (BMU) both sponsor R&D activities in this area.

[42]German Research Society (DFG), 1998. *Jahresbericht 1997: Aufgaben und Ergebnisse (Auszüge)* http://www.dfg-bonn.de/ergebnisse_programme_projekte/jb97/1/2/#1

[43] BMBF, 1997. *Basic and Structural Data 1996/97*, p. 160.

[44] BMBF, 1997. *Basic and Structural Data 1996/97*, p. 144.