Energy R&D in the European Union

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Introduction: Research and Development in the European Union

The European Union (EU) is a major sponsor of research and development activities in many socioeconomic areas. EU-sponsored research projects aim to support and advance overarching Community policy goals such as European integration, capacity development, and European leadership in science and technology. The main vehicle of EU-sponsored R&D is the Framework Programme for Research and Technological Development, a multi-year plan drafted by the European Commission and approved by the Council of Ministers and the European Parliament with input from the individual EU member states. The Framework Programme establishes legal and administrative structure, scientific and technical objectives, and provides financial resources for the conduct of research. The Sixth Framework Programme (FP 6) began in 2002 and will continue through 2006. With a budget of $17.6 billion, as shown in Figure 1, FP 6 represents an estimated 4-5% of aggregate R&D expenditure of EU member states.¹

Figure 1. Framework Programme Budgets 1984-2002

¹ This report focuses exclusively on the research and development programs administered at the Community level by the European Commission. It does not address any of the R&D programs funded and directly at the national or state/provincial level within any individual European Union (EU) member state. Thus, the R&D expenditures described here should be regarded as distinct from the domestic R&D expenditures of EU member states.
The Framework Programme is financed through the general budget of the European Union, consisting of member states’ financial contributions. Projects that receive Framework Programme support must involve participants from industry, universities, and laboratories from at least two EU countries. Projects are selected competitively on the basis of scientific merit and relevance to EU policy goals. Thus, countries that contribute larger shares to the EU budget cannot necessarily expect their research institutions to receive corresponding shares of research funding from Brussels.

Figure 1 shows the EU’s R&D expenditures in Framework Programmes 1-6, covering the period 1984-2006. Since its inception in 1984, the Framework Programme has grown significantly in its technical scope, in the resources devoted to it, and in its overall importance to the achievement of EU policy goals. Between the First and Sixth Framework Programmes, the EU’s total research expenditure has grown in real terms by 250%, from $6.8 billion to $17.6 billion. Figure 2 provides a breakdown of the Sixth Framework Programme (FP6) budget.

Figure 2. Breakdown of Framework Programme 6 Budget by Major Research Area (Total: $17.6 billion)

As Figure 2 shows, Framework Programme 6 covers a wide range of research in the natural, engineering, and social sciences. Historically, a majority of the Programme’s resources (more than 85%) has been directed to the development of new technologies in selected socioeconomic areas including information and telecommunications, materials research, biotechnology, energy, health, and the environment. In this regard, the Framework Programme structure provides an important vehicle for the development of...
European science and technology capacity and for European competitiveness in the global marketplace.

A main objective of FP6 is to foster the creation of a European Research Area (ERA) by integrating and coordinating European research. The ERA initiative grew out of the recognition that European research is hampered by three weaknesses: insufficient funding, a sub-optimal environment for innovation and the exploitation of research results, and the fragmented nature in which research is funded and performed in Europe.\(^{4}\)

The EU invests only 1.9% of its GDP in R&D, whereas the U.S. and Japan invest 2.7% and 3% respectively, as illustrated in Figure 3 below. Europe also lags behind the U.S. and Japan in number of patent applications and its trade balance in high technology products is in deficit. In addition, more than 80% of R&D conducted in the EU is funded at the national level, with little coordination among national efforts. The ERA initiative addresses these deficiencies in European research and seeks to augment levels of resources and intra-European R&D cooperation.\(^ {5}\)

**Figure 3. Public and Private Sector Research Expenditures (%GDP) in Industrialized Countries 1998/1999\(^{6}\)**

A corresponding policy goal of the Framework Programme is to strengthen European economic competitiveness by building the technical and technological foundations of industry. In addition, specific research objectives under FP 6 focus on major traditional socioeconomic research areas including information technology, life sciences and biotechnology, environmental science, and space research. The Programme also has important social goals such as the advancement of women in the sciences and the
development of scientific knowledge and infrastructure, particularly in EU member states that are relatively underdeveloped in this regard.\textsuperscript{7}

FP 6 emphasizes seven major research areas in its efforts to focus and integrate European research. These priority research areas are those in which the EU intends, in the medium term, to achieve global leadership. Table 1 shows the FP 6 thematic priorities and corresponding main research areas.

\begin{table}[h]
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\begin{tabular}{|l|l|l|l|l|l|}
\hline
\textbf{Selected Key R&D Areas} & \textbf{Life Sciences, Genomics, and Biotechnology} & \textbf{Information Society Technologies} & \textbf{Nano-technologies \& Sciences} & \textbf{Aeronautics} & \textbf{Sustainable Development} \\
\hline
- Advanced genomics and health applications & - Advanced genomics and health applications & - Applied IST research addressing social and economic challenges and complex problem-solving & - Nano-technologies and nano-sciences & - Aircraft safety & - Sustainable energy systems \\
- Combating major diseases & - Communication, computing, and software technologies & - Knowledge-based multifunction materials & - New production processes and devices & - Emissions and noise & - Sustainable surface transport \\
 & - Knowledge \& interface technologies & - New production processes and devices & - Galileo & - Satellite telecommunications & - Global change and ecosystem research \\
 & - Emerging technologies & - Galileo & - Epidemiology of food-related disease & & - Social cohesion in the knowledge society \\
\hline
\end{tabular}
\caption{Thematic Priorities of EU Sixth Framework Programme}\textsuperscript{8}
\end{table}

Since the inception of the Framework Programme as the major vehicle for European research, there have been significant shifts in policy priorities and research emphases. In FP1 (1984-1987) for example, nearly 50\% ($3 billion) of the budget was devoted to energy R&D. The prominence of energy R&D then reflected the recent memory of the 1970s oil crises in the European policy establishment. Throughout the 1970s and early 1980s, energy occupied a central position in Community-sponsored research because of the severe economic dislocation inflicted by the 1973-74 and 1979-80 oil supply shocks. Subsequently, however, events such as the passage of the Single European Act in 1986 placed increasing emphasis on European integration, removal of internal economic barriers, and the creation of a single European market and currency. European governments’ rising concerns with global economic competitiveness and technological leadership began to emerge as primary policy goals and, as such, featured more prominently in subsequent Framework Programme research. Thus, in the FP 2 and FP 3...
budgets, fewer resources were devoted to energy, while industrial research grew to a share of more than 60%. Energy’s share of the Framework Programme budget has declined consistently since FP1. In FP6, energy R&D constitutes 14% ($1.2 billion) of the total budget, reflecting the overall expansion of the Framework Programme’s scope, shifting and proliferating policy priorities, and the corresponding need for the EU to stretch its research resources farther.\textsuperscript{9}
Energy Policy

Energy policy in the European Union addresses three major issues that concern all Member States: the challenge of energy security, environmental impacts of energy use, and the continuation of energy deregulation and system integration across the EU. With regard to energy security, EU energy policy focuses primarily on the problem of rising energy import dependence and the political constraints that are likely to stem from steadily rising levels of energy dependence. The main environmental issue considered by EU energy policy is that of global climate change. EU energy policy seeks to coordinate Member States’ efforts to reduce emissions of carbon and other greenhouse gases and to spur deeper cuts in the EU’s overall emissions profile. Energy policy in the EU also encourages the ongoing harmonization of national legal and regulatory regimes as they relate to networked energy systems, and promotes the integration of European energy markets.

Energy Security. Rising levels of energy import dependence could impose significant geopolitical and foreign policy constraints on the EU. Currently, the EU imports roughly half of its energy resources. In its recently published “Green Paper on Energy Security,” the European Commission estimates that over the next 20 to 30 years, energy import dependence will rise to 70% overall and up to 90% for oil, in the absence of policy action in the near term to reduce dependence. One aspect of import dependence that raises concern in Europe is the increasing dominance of OPEC producers in the European fuel mix. OPEC currently supplies 51% of EU oil supplies, and the majority of that share originates in the Middle East. Also, since indigenous production is now declining, an increasing share of the EU’s natural gas supply comes from Algeria, Russia, and Norway, deepening Europe’s overall fossil fuel import dependence.

Even where the EU has more abundant indigenous energy resources—coal, nuclear power, and renewable resources—economic and political constraints could limit their role in the future European fuel mix. For example, while Europe has large reserves of coal and uranium, production costs for these resources exceed current world market prices. Also, the future of nuclear power is now being debated across Europe, where environmental and safety concerns have prompted several countries including Germany, the United Kingdom, and Italy to attempt complete nuclear phase-outs over the coming decades. Whether to extend the licenses of aging nuclear plants, replace them with fossil plants, or invest more heavily in the development of renewable energy sources and technologies will be one of the major energy issues to be resolved in the EU in coming years.

The European Commission has proposed a multi-pronged approach to energy security that includes both supply- and demand-side policy components. On the supply side, the EU is engaged in discussions with the Russian government regarding a strategic energy partnership designed to reduce OPEC dependence. The EU has proposed significant new investments in the development of Russian energy resources in exchange for guarantees regarding access to Russian oil and gas.
The EU also intends to diversify energy supply by promoting the development of renewable energy resources such as biofuels. The European Commission has introduced regulatory and fiscal policy proposals promoting biofuels with the aim of 5.75% biofuels penetration of the liquid fuels market by 2010. With additional incentives, the Commission believes it is possible for biofuels to replace up to 20% of gasoline and diesel consumption by 2020.13

In 2001, the European Commission also adopted a Directive on electricity production from renewable sources, under which EU member states are to comply with national targets for the use of increasing shares of renewable energy in the power production fuel mix. The Directive has established a system of certification for “green electricity” sources and introduces accompanying policy incentives for the market penetration of renewably-generated electricity. The aim of this regulatory framework is for green power to achieve 22% penetration EU-wide by 2010.14

Energy demand management features prominently in the Green Paper on Energy Security, which recognizes the fact that Europe has relatively little room to maneuver with regard to energy supply. The Green paper states clearly that demand must be guided and steered through the use of taxes and other policy measures aimed at significantly increasing energy efficiency in all sectors. The Commission suggests, for example, that tax incentives could be used to reduce energy consumption in buildings by 22% over the next decade and to reduce overall energy consumption across the EU by as much as 10% by 2010.15

**Climate Change.** In May 2002, the European Union and its member states ratified the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Under that treaty, the EU is legally obligated to reduce its cumulative emissions of six key greenhouse gases within the period 2008-2012. Member states each have different emissions reduction obligations within the “EU bubble,” whereby some countries must make large emissions cuts while others are allowed to increase their emissions. Germany and Denmark, for example, have committed to 21% cuts from 1990 levels by 2008-2012, while Portugal and Greece are allowed emissions increases of 27% and 25%, respectively. These commitments reflect the differences in level of economic development and in emissions levels among EU countries, and place larger burdens on countries accordingly. Cumulatively, the EU is now approximately 0.5% above its targeted greenhouse gas emissions trajectory.16

To help the EU meet its commitments under the Kyoto Protocol, the Commission developed a series of priority actions and policy measures and in 2000 launched the European Climate Change Programme (ECCP). The Programme addresses all economic sectors, devoting considerable attention to energy supply and to its consumption in transportation, industry, and buildings. For example, the ECCP aims to reduce carbon dioxide emissions by promoting better management of electricity transmission and distribution networks and the broader use of combined heat and power, renewable energy, and fuel cell technologies. Enabling these technologies to gain access to the
European electricity grid is a key issue. The Programme also includes policy measures encouraging the capture and disposal or reuse of carbon dioxide, and the decarbonization of fossil fuels prior to combustion. Continued integration of the EU’s networked energy systems (discussed in greater detail below) is seen as a lynchpin for the more efficient use of energy and the reduction of overall greenhouse gas emissions.17

The ECCP’s demand-side measures aim to boost energy efficiency in all major sectors through, for example, the use of more rigorous codes and standards for building design and performance, improvements in lighting, boiler, and appliance performance, and incentives for better insulation. The ECCP includes a labeling initiative and database that aims to assist consumers in making more informed purchasing decisions. In the industrial sector, the Programme includes a best practices program and provides tax incentives for the adoption of best available technologies.18

Under the ECCP, a number of flexibility mechanisms have been adopted to help reduce the economic costs associated with meeting the Kyoto emissions reduction targets. In addition to the joint implementation and clean development mechanisms included in the Kyoto Protocol, the EU has created the world’s first international greenhouse gas emissions trading regime. The plan caps carbon dioxide emissions (which alone account for 95% of the EU’s greenhouse gas emissions) from several sectors, including electric power, beginning in 2005, and distributes allowances to each of these industries. Companies using less than their emissions allotment may then sell the remainder to firms with higher emissions. Companies that violate the emissions cap will initially face fines of €40 per ton of carbon; the fine for violators will rise to €100 in 2008. Additional greenhouse gases, including methane, will be added to the emissions trading system later. Through its institution of the world’s first regional carbon trading regime, the EU hopes to position itself well to participate in the global emissions trading scheme envisioned by the Kyoto Protocol.19

Liberalization and Integration of Energy Networks. Under Article 14 of the Treaty of Rome, which established the European Community, the Community is responsible for creating a market without internal barriers to the movement of goods, services, capital, and people. While the EU has fully realized the intent of the Treaty of Rome in many areas, there is still a large amount of work to be done in integrating Europe’s energy markets and infrastructures, particularly those for electricity and natural gas. The integration of Europe’s networked energy systems is considered a strategic objective for the EU, since it will make significant contributions to energy security by enhancing supply flexibility. Integration is also regarded as pivotal to the competitiveness of energy markets, and thus, to the lowering of consumer energy prices. Since the early 1990s, the European Commission has adopted Directives on the integration of gas and electricity markets aiming to open them to competition, while also expanding Europe’s energy infrastructure.20

Although all EU member states have made significant progress in liberalizing their energy industries domestically, there are still many obstacles to network access that
hinder cross-border transactions. A key problem is the fact that implementation of the directives on electricity and gas market liberalization has occurred at different rates in different countries, as Table 2 shows. While some countries, such as Germany, Finland, and the United Kingdom, have completed the deregulation of domestic energy industries and markets, allowing all consumers to choose their energy providers, other countries still lag in this regard. The EU Directives mandate that all consumers be granted the right to choose their electricity and gas suppliers by January 2005 at the latest.21

### Table 2. EU Electricity and Gas Market Opening 2000

<table>
<thead>
<tr>
<th>Directive Mandated Minimum Opening</th>
<th>Electricity</th>
<th>Gas</th>
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<tbody>
<tr>
<td>Austria</td>
<td>32%</td>
<td>49%</td>
</tr>
<tr>
<td>Belgium</td>
<td>35%</td>
<td>59%</td>
</tr>
<tr>
<td>Denmark</td>
<td>90%</td>
<td>30%</td>
</tr>
<tr>
<td>Finland</td>
<td>100%</td>
<td>90%</td>
</tr>
<tr>
<td>France</td>
<td>30%</td>
<td>20%</td>
</tr>
<tr>
<td>Germany</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Greece</td>
<td>30%</td>
<td>0%</td>
</tr>
<tr>
<td>Ireland</td>
<td>30%</td>
<td>75%</td>
</tr>
<tr>
<td>Italy</td>
<td>35%</td>
<td>96%</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>40%</td>
<td>51%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>33%</td>
<td>45%</td>
</tr>
<tr>
<td>Portugal</td>
<td>30%</td>
<td>0%</td>
</tr>
<tr>
<td>Spain</td>
<td>54%</td>
<td>72%</td>
</tr>
<tr>
<td>Sweden</td>
<td>100%</td>
<td>47%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>EU Average</strong></td>
<td><strong>66%</strong></td>
<td><strong>79%</strong></td>
</tr>
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Other key issues must also be resolved, including agreement on tariffs for access to energy transmission networks. The main objective of EU policy in this regard is to ensure that there are transparent and non-discriminatory rules on the allocation of Europe’s limited electricity and gas interconnection capacity. Transmission system operators will be allowed to impose network access charges that reflect their costs, yet that do not offer preferential rates and access to individual providers. Rules must also be established determining transit costs and regulating compensation to transmission system operators. Expansion of Europe’s gas and electricity networks and interconnections among them will also remain an important priority.23

The expansion and development of EU energy networks is an important component of energy security policy. With regard to natural gas networks in particular, the EU is seeking interconnectivity with several countries beyond its own borders in an effort to diversify its gas supply. Since natural gas accounts for an increasing share of European energy demand (especially for power generation), ensuring flexibility of supply is a major policy goal. In addition to its pipeline linkages with Russia, agreements and
pipeline connections are being sought with Algeria and other Mediterranean Basin countries, and with Central Asian countries.²⁴

**Energy R&D**

Non-nuclear energy R&D in the European Union is performed under the general Framework Programme for Research and Technological Development. All nuclear energy R&D (fission, fusion, and radiation safety research) is funded and performed under a separate EU research program, the Euratom Framework Programme. The current research programs for nuclear and non-nuclear energy R&D cover the years 2002-2006 and have budgets of $1.2 billion and $815 million, respectively.²⁵

Energy has been a core component of European integration since the inception of the European Communities following World War II. Two of the three founding treaties of the European Union, the European Coal and Steel Community and the European Atomic Energy Community, are based on the need for cooperation and coordination among European countries in the management of energy resources and markets. Likewise, since the establishment of the Framework Programme for Research and Technological Development in the early 1980s, energy R&D has featured prominently on the European research agenda.²⁶

While energy R&D remains a key element of the European Framework Programme, its share of the EU R&D budget has shrunk significantly over the past two decades, as Figure 3 shows.

**Figure 4. Energy R&D as a Percentage of EU Framework Programme Budget, 1984-2006**
Each new Framework Programme has brought a new and expanded set of ideas and policy priorities. Corresponding with the expansion of the European Union itself, the Framework Programme has grown steadily in scope and resources. Even with the continual growth in the Programme’s budget, however, emerging research programs and shifting policy priorities have spurred competition and crowding out among research areas. More than any other area, energy R&D has yielded resources to other policy priorities over time. R&D Figure 4 below shows the evolution of EU research policy priorities between 1984 and 2006.

**Figure 5. Evolving Research Priorities in the European Union**

Under the Sixth Framework Programme, energy R&D supports the broad policy objective of creating sustainable energy systems. In this regard, the research program’s strategic and policy objectives include the reduction of energy-related greenhouse gas emissions as mandated by the Kyoto Protocol, enhancing European energy security, improving energy efficiency and productivity, and accelerating the adoption of renewable energy technologies. Crosscutting each of these goals is the aim of promoting the competitiveness of European industry and improving living standards and quality of life throughout the EU.

Under the Sixth Framework Programme’s Sustainable Energy Systems Work Programme, activities are grouped in two main categories: activities having an impact in the short- to medium-term, and activities having an impact in the medium- and longer-term. Short- to medium-term activities include research on renewable energy systems and their integration into the existing infrastructure, and research into conservation and...
energy efficiency; medium- to longer-term R&D activities concentrate on the
development of emerging technologies including hydrogen and fuel cells, and carbon
capture and sequestration. Descriptions of major EU-sponsored non-nuclear and nuclear
energy R&D activities under the Sixth Framework Programme are provided below.29

Non-Nuclear Energy R&D in the Sixth Framework Programme
($815 million, 2002-2006)

Renewable Energy
EU-sponsored renewable energy research focuses on bringing the next generation of
more cost-effective renewable energy technologies to market, with emphasis on
European markets. Sponsored projects are expected to yield technologies that are
capable of competing in the liberalized market place with little or no government subsidy.
Primarily, renewable energy research seeks to reduce the costs associated with
renewably-generated energy in the form of green electricity, heating and cooling, and
liquid and gaseous biofuels.

Biomass. The biomass program focuses on the production of electricity from energy
crops and on waste derived fuels. Projects focus on: optimization of the fuel supply chain
considering all aspects of fuel production and preparation of fuel to high standard and
specifications; combination of biofuels with fossil fuels to guarantee uninterrupted
electricity supply; and innovative technologies for large scale power generation such as
integrated gasification combined cycle (IGCC) plants, biomass boilers, and flash
pyrolysis applications emphasizing high conversion efficiencies. Longer term research
projects focus on the development of reliable and cost effective combustion technologies
that minimize waste streams, operation of large-scale systems with multifuel capability,
and reliable and cost-effective gasification systems. Long-term research also focuses on
cost-effective lignocellulosic biofuels production for use in both combustion engines and
fuel cells, and on biofuels production from bioresidues and energy crops. These efforts
seek to reduce the cost of biomass electricity production to 0.05 Euro/kWh and the cost
of biofuels to €10/GJ by 2020.30

Wind. Projects sponsored under the 6th Framework Programme focus on the development
of innovative turbines, components, and related design tools that can be used to reduce
the cost of wind-generated electricity onshore and offshore. Wind energy R&D also
includes modeling of large, multi-megawatt turbines and site assessment, and research
into new materials, enhanced aerodynamics, and design principles. Research in this area
also addresses constraints to the broader deployment of wind turbines in unconventional
settings such as offshore sites, cold climates, and difficult terrain and seeks to develop
and demonstrate new control technologies to ensure grid stability.31

Solar Photovoltaics (PV). Priorities include innovative production concepts for high
efficiency PV cells and modules for integration with large-scale PV production to reduce
the cost of solar-generated electricity. Activities supporting this goal include:
stimulation of silicon production by EU industry to ensure an adequate and affordable supply for European PV cell manufacturers; transfer of new generation PV technologies to industrial scale production and deployment; and integration of PV installations in power generation systems to feed local distribution grids closer to point of end use. Longer-term research focuses on the development of next generation technologies such as organic or hybrid solar cells, thin film PV technology, automated manufacturing technologies, system component and integration, and innovative applications of PV technology in buildings and the built environment. Long-term research aims to reduce the investment cost for PV systems to €1-2/Wp and to cut retail PV electricity costs to €0.1/kWh by 2015.\textsuperscript{32}

\textit{Electric Power Production from Other Renewable Sources.} The EU supports a small research program exploring the potential for the large-scale solar thermal generation of electricity from power tower, dish, and trough technologies. Similarly, support for geothermal energy technology focuses on electric power generation, combined heat and power plants, and use of geothermal energy for heating and cooling applications. Small-scale hydropower research aims to reduce both the costs and environmental impacts associated with hydropower production. The EU’s small energy technology program includes wave, ocean current, and tidal technologies that are now ready for full-scale demonstration or commercialization.\textsuperscript{33}

\textit{Heating & Cooling from Renewable Energy Sources.} Projects sponsored under this program focus on innovative application of biofuels and waste derived fuels for power production in industrial facilities and buildings; solar heating and cooling using new solar technologies for water and space heating and cooling; solar industrial process heating and desalination systems; and geothermal energy for heating and cooling using technologies that are environmentally sustainable and cost-competitive.\textsuperscript{34}

\textit{Production and Processing of Liquid Biofuels.} This program includes research on the production of alcohol-based fuels, ether, biodiesel, and biogas. Priority is given to processing technologies via the synthesis gas route and enzymatic conversion of lignocellulose to ethanol. Activities in this area also include a wide array of research projects addressing the entire biofuel cycle from energy crop production, short rotation coppice, harvesting and drying techniques, and biofuel production and marketing techniques.\textsuperscript{35}

\textit{Large-Scale Integration of Renewables into Energy Supply.} Since the European Union has set ambitious goals for the penetration of renewable energy sources in its overall fuel mix, for reductions in energy intensity, and for the reduction of CO\textsubscript{2} emissions, a portion of the energy R&D resources under the 6\textsuperscript{th} Framework Programme focus on the integration of renewable technologies into the EU’s energy systems. In this context, priority is given to two types of activity: 1.) research activities that contribute to a better understanding of the potential problems and challenges associated with broader use of distributed generation in existing power and heat distribution grids; and 2.) large-scale integration projects in clearly-defined geographic areas where all relevant energy flows can be identified, measured, and assessed. These projects involve partnerships among a
variety of actors including community groups, utilities, industry, and local government agencies. Each also addresses innovative technical approaches to the production, storage, and integration of renewable and non-renewable systems.36

**Energy Conservation and Efficiency**

Energy efficiency R&D in the 6th Framework Programme supports several EU energy policy goals including: 1.) reducing energy intensity by 18% by 2010; 2.) achieving a community-wide target of 18% of electricity production from cogeneration by 2010; 3.) doubling the share of renewables in the fuel mix to 12% by 2010; and 4.) enhancing Europe’s overall energy security through demand management. Each of the major research categories in the energy conservation and efficiency R&D program, eco-buildings and polygeneration, is discussed below.

**Eco-buildings.** The building sector accounts for 40% of European energy consumption. Thus, efforts to reduce energy demand in existing and new buildings is regarded as a key to reducing energy intensity in the EU. The eco-buildings program combines short-term development and demonstration projects in support of legislative and regulatory measures for energy efficiency in the buildings sector. Projects aim to create new approaches to building design, construction, and renovation methods to reduce heating, cooling, and lighting energy demands. It includes support for the application of new knowledge to the development of new codes and standards and for the innovative use of advanced control technologies, telecommunications and information tools in buildings energy management systems.37

**Polygeneration.** Polygeneration refers to the combined production of electricity, heat, cold, and other products (e.g., hydrogen, chemicals), district heating and cooling and other energy services. Research in this area seeks to control energy intensity in buildings and industry by stimulating market penetration of cogeneration, trigeneration, and polygeneration technologies for residential, commercial, and industrial buildings. Polygeneration research also aims to increase the flexibility of the electric power system, considering the ongoing liberalization of that industry, by improving the interaction of large and small producers of heat and power to increase overall efficiency and grid stability.38

**Alternative Motor Fuels**

The European Commission has set ambitious targets for the development of cleaner and more energy efficient transportation fuels, consistent with its emissions reduction commitments under the Kyoto Protocol and its broader commitment to sustainable development. The Commission has set an EU-wide target of 20% substitution of alternative fuels in the transportation sector by 2020 and aims to meet this objective by focusing its R&D resources on three fuels that could play key roles: natural gas, hydrogen, and biofuels.
Short- to medium-term research projects focus on actions to identify and assess technical and institutional barriers to the wider adoption of alternative transportation fuel technologies. Since urban areas present some of the most pressing transportation challenges, the program focuses on new and alternative fuel distribution and refueling infrastructure, particularly for fleet vehicles in cities.  

**Fuel Cell Research**

The European Commission considers the fuel cell a strategic and potentially transformative energy technology over the medium- to longer-term and, consequently, devotes significant resources under the Sixth Framework Programme to their continued development, demonstration, and integration into existing energy systems. Research focuses on the development of economically-competitive fuel cell production and related technologies for stationary and transportation uses, covering both low temperature fuel cell systems (e.g., stacks, fuel processors, reversible fuel cell electrolysers) and fuel cell systems applications. Materials, processes, and component level development are all key areas of emphasis, all of which aim to improve fuel cell performance and durability, and reduce costs.

The EU fuel cell program has several technological focus areas including:

- *Development of low-cost, competitive high temperature fuel cells for decentralized power generation.* Research aims to develop cost-effective, safe, and reliable fuel cell systems for electricity production covering power ranges from 0.5 MW to 5 MW, with an installed cost of less than €1000/kW and service lives of more than 40,000 hours.

- *Development of solid polymer fuel cells and components for stationary and transport applications.* The main research goal is to enable production of solid polymer fuel cells that with a cost of less than €100 for stationary and €50 for transportation applications, with service lives of 30,000 and 5,000 hours, respectively. Research integrates modeling, materials, catalysis, on-board fuel processors, energy/environmental life cycle analyses and policy analysis in the effort to develop fuel cell energy systems.

- *Development of new knowledge, materials, processes, and components for proton exchange membrane (PEM) and direct methanol (DM) fuel cells.* The objective is to advance knowledge of related materials physics, electro-chemistry, and economic analyses to eliminate barriers to the mass production and wide deployment of low-temperature fuel cells.

- *Development of fuel cells for small, portable applications.* This research program aims to develop safe, clean, and reliable fuel cells of a few hundred watts to power small, portable devices.

- *Development and validation of “next generation” computational and simulation tools for fuel cell systems analysis.* Efforts focus on the continued advancement of analytical support tools focusing on thermodynamics, reactor performance, heat integration, etc. and particularly on industrial applications.
Consultation with a Community of Experts on Fuel Cells and Hydrogen. In addition to its R&D activities, the Commission has formed a High Level Group on Hydrogen and Fuel Cells consisting of experts and key stakeholders from government, industry, and academia to explore the potential for, and challenges to, the development of European leadership in the production and adoption of fuel cells and related technologies. The group’s main objective is to produce a “foresight” report on hydrogen and fuel cells as a bridge to sustainable energy systems, including scenarios, technology roadmapping, and deployment strategies.41

Hydrogen Research
The European Commission believes that hydrogen and electricity, together with fuel cells, have great potential as interlinked energy carriers for a more environmentally sustainable and secure energy future. The transition to sustainable energy systems demands the widespread diffusion of both renewable and hydrogen-based energy technologies for the large scale adoption of distributed energy production. In this regard, EU-sponsored hydrogen research focuses on long-term efforts in several technology areas including:

- Identification, development, and validation of cost-effective technologies for centralized and decentralized hydrogen production from fossil, renewable, and other sources.
- Evaluation and development of safe, cost-effective storage media and related infrastructure for stationary and transportation applications, focusing on next generation storage systems, on-board systems for transportation systems, and new materials.
- Technology mapping, socioeconomic and policy research aiming to identify and address barriers to the development of a hydrogen economy.
- Novel concepts and advanced components for power transmission and distribution networks to promote the market penetration of distributed energy resources. Research aims to enable the development of intelligent power networks incorporating advanced information and communications technologies in the grid management system and enabling technology manufacturers to plan and validate industrial production of grid control and management devices.

Carbon Capture and Sequestration
Because Europe’s fuel mix will remain dominated by fossil fuels for the foreseeable future, carbon capture and sequestration research features prominently in the EU’s energy R&D program under the Sixth Framework Programme. Carbon capture and sequestration technologies may play a key role in allowing the EU to make its fossil fuel consumption more compatible with its ambitious policy targets for CO2 emissions reduction and climate change mitigation. Research focuses on several technology areas including:
• Development of pre-combustion CO₂ capture technologies. The main objective of research in this area is the validation of capture technologies that have been demonstrated in small power plants for broader application in full-scale applications. An important research aim is to demonstrate the technical and economic viability of carbon capture technologies for hydrogen production from fossil fuels. Reducing the cost of carbon capture from their current level of €50-60/tonne to €20-30 per ton while achieving capture rates >90% is an important research aim.42

• Development of post-combustion CO₂ capture technologies. The main research objectives are to assess technological and economic feasibility of carbon sequestration at full-scale power plants and to gain hands on experience with pilot sequestration projects, such as the SACS programme, which experiments with the injection of captured carbon into a saline aquifer in the Sleipner area of the Norwegian North Sea.43

• Development of CO₂ Capture and Geological Sequestration as a Viable Option for CO₂ Mitigation. Main research aims include the integration of power generation research with carbon capture and sequestration activities, such as those begun under the Fifth Framework Programme’s Advanced Zero Emissions Powerplant (AZEP) programme. Research aims to develop techniques for the monitoring of sequestered carbon and the assessment of safety and reliability, environmental impacts, and socio-economic viability.44

• Chemical and Mineral Carbon Sequestration. Research assesses the viability of other sequestration media including magnesium, silicon, and other carbonates, as well as other innovative/commercial uses of sequestered carbon.

• Transport of CO₂. Research focuses on the economic and technical challenges associated with the development of transport facilities and infrastructure, on the networks needed for large-scale capture and storage, and on the materials requirements for safe and reliable carbon transport networks.45

Nuclear Energy R&D in the Sixth Framework Programme
($1.23 billion, 2002-2006)

Nuclear energy and related R&D have been cornerstones of the European Union since its birth in the aftermath of the Second World War. One of the founding treaties of the European Union established the European Atomic Energy Commission in 1958 as a framework for coordinated effort among European countries to realize the potential of nuclear power. Nuclear energy research remains an important component of the EU research program in the Sixth Framework Programme, as it has in each of the previous Framework Programmes. The EU conducts R&D in the areas of fission, fusion, radiation protection, and waste management through a dedicated, parallel Framework Programme.46
Nuclear Fission Research

EU-sponsored fission R&D aims to fully exploit the potential of nuclear power in the short- and medium-term to further the policy goals of environmental sustainability, energy security, and climate change mitigation. A key short-term goal is to resolve the issue of nuclear waste disposal by finding a safe and permanent geologic disposal site. Enhancing nuclear safety and radiation protection at existing plants across Europe is also a central research focus.47 Fission energy R&D research programs sponsored by the EU include:

Management of Radioactive Waste.48

The main focus of radioactive waste research is the development of technologies that will facilitate a greater degree of consensus on questions of waste management and disposal. There are four main areas of focus in the waste management research program:

- **Geological disposal** aims to find technologically sound solutions for the safe disposal of spent fuel and long-lived waste in geological repositories. This program seeks to improve basic knowledge of key processes, develop and test disposal technologies, and improve decision-making processes related to waste management.

- **Partitioning and Transmutation** seeks practical ways of reducing the amount of long-lived radionuclides and develops chemical separation (partitioning) and transmutation (radionuclide conversion) techniques.

- **Reducing Waste Production** aims to find more efficient ways of using fissile materials in existing reactors and study new concepts to minimize waste production in nuclear power generation.

- **Cross-cutting Research for Radioactive Waste Management** aims to strengthen and integrate European research activities on the chemistry and physics of actinides and to study the behavior of actinides in spent fuel, in the geological environment, in the partitioning process, and in new fuel types.

Innovative, Safer, and More Efficient Power Plants49

Evaluating the potential of new and innovative concepts for nuclear power production is an important part of the EU’s nuclear research program. Key themes in this research area include high temperature reactor design and evaluation and other applications of nuclear power such as hydrogen production using process heat from nuclear fission systems.

Safety of Existing Nuclear Installations50

Nuclear facility safety research strives to continually improve European nuclear safety standards and performance, and to develop a common scientific foundation for EU-wide safety standards. Activities in this program area include:
• Plant Life Management develops risk assessment methodologies and analyzes high fuel burn-up.
• Severe Accident Phenomenology and Management supports the development of advanced, common numerical simulation tools for major nuclear accidents.
• Decommissioning Research focuses on the coordination of scientific and technological activities across Europe, on the improvement and maintenance of the existing decommissioning databank, and on the organization of training activities.

Radiation Protection
The primary focus of the EU’s radiation research program is risk reduction associated with exposure to low and protracted doses of radiation as experienced by workers in the nuclear power industry. Research includes epidemiological studies of exposed populations and cellular and molecular biology research on the interactions of radiation with DNA, cells, organs, and the body as a whole. Research areas include:

• Medical Exposure and Natural Sources of Radiation aims to enhance the safety and efficacy of medical uses of radiation in diagnosis and therapy, and to promote the development of common policies throughout the EU regarding the management and control of natural sources of exposure.
• Protection of the Environment and Radioecology seeks to establish common policies and standards to protect the environment from radiation and to integrate European research on radioecology.
• Risk and Emergency Management develops new risk assessment and management methods with the aim of improving the applications of nuclear safety technologies and broadening the public acceptance of nuclear power.

Nuclear Fusion Research
The European Commission considers fusion an important long-term technological option for energy supply. EU-sponsored fusion research focuses on demonstrating the scientific and technological feasibility of fusion energy and assessing its commercial potential. Under the EURATOM Sixth Framework Programme, there are three major research programs, discussed below.

Fusion Physics and Technology
The fusion physics program encompasses R&D in plasma engineering and fusion materials. In addition, the program sponsors research needed for the decommissioning of the European Union’s Joint European Torus (JET) experimental fusion reactor in Oxford, UK. Economic and policy research, and studies of the social acceptability of fusion energy, are also funded by the fusion physics program.
**Operation and Use of the JET Facilities**

JET is a cornerstone of the European fusion programme, which aims to harness the power of nuclear fusion to create safe and environmentally friendly energy. It is the only machine capable of operating with the fuel mixture that will be used in a commercial fusion power station. Since January 2000, the JET experiment has been operated by UKAEA under the European fusion development agreement (EFDA). The JET experiment has also become an increasing focus for European cooperation. The facility draws scientists and engineers from associated laboratories across Europe, as well as from associated and third countries, to carry out experiments in the integrated European fusion programme. The main aim of JET is to enable study of the conditions and dimensions needed in a power plant. It will be succeeded by the internationally-funded machine ITER (the international thermonuclear experimental reactor), followed by a demonstration fusion power plant.53

**International Thermonuclear Experimental Reactor (ITER)**

The overall programmatic objective of ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. ITER would accomplish this objective by demonstrating controlled ignition and extended burn of deuterium-tritium plasmas, with steady-state as an ultimate goal, by demonstrating technologies essential to a reactor in an integrated system, and by performing integrated testing of high heat-flux and nuclear components required to utilize fusion energy for practical purposes. The ITER program, launched in 1987, is considered the “next step” beyond the JET program. This multilateral research program includes the U.S., Russia, Japan, and the EU as equal partners in the Conceptual Design Activities (CDA) for the International Thermonuclear Experimental Reactor. The ITER CDA phase was successfully concluded in 1990. The ITER Engineering Design Activities (EDA) started in 1992 in the frame of the quadripartite Agreement among Euratom and the governments of Japan, the Russian Federation and the USA. The ITER-EDA is conducted by the four ITER Parties under the auspices of the IAEA and carried out by a Joint Central Team (JCT) located in three internationally staffed co-centers in San Diego (USA), Naka (Japan) and Garching, (Germany).54

The Sixth Euratom Framework Programme includes additional research activities in preparation for European participation in the construction of ITER. A decision on whether or not to proceed is expected in 2003-2004, which would allow construction to begin in 2005 at the earliest.55

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2 Community Research and Development Information Service (CORDIS), http://www.cordis.lu.
3 Community Research and Development Information Service (CORDIS), http://www.cordis.lu.
9 This estimate combines non-nuclear energy research performed under the Sixth Framework Programme with nuclear research performed under the Euratom Framework Programme 6.