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Key Energy Technologies for Europe

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September 2005

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This report on key energy technologies is part of the work undertaken by the High-Level Expert Group to prepare a report on emerging science and technology trends and the implications for EU and Member State research policies.

Senior Scientist Birte Holst Jørgensen, Risø National Laboratory, is responsible for the report, which is based on literature studies. Postdoc Stefan Krüger Nielsen, Risø National Laboratory, has contributed to parts of the report, including the description of the IEA energy scenarios, the IEA statistics on R&D and the description of the science and technology base of biomass.

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Valuable help and comments to earlier drafts of this report have been contributed by Scientific Officer Edgar Thielmann, DG TREN, Head of Department Hans Larsen, Risø National Laboratory, Senior Asset Manager Aksel Hauge Pedersen, DONG VE, Consultant Timon Wehnert, IZT-Berlin, and Senior Scientist Martine Uyterlinde, ECN

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Preface

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Abbreviations

AGE	Advisory Group on Energy to DG Research
CBF	Circulating Fluidised Bed
CHP	Combined Heat and Power
CSLF	Carbon Sequestration Leadership Forum
CUTE/ECTOS	Clean Urban Transport in Europe / Ecological City Transport System
ECBM	Enhanced Coal Bed Methane
EERA	European Energy Research Area
EGR	Enhanced Gas Recovery
EIE	Intelligent Energy Europe
EOR	Enhanced Oil Recovery
EPR	European Pressurised Reactor
EWOG	Energy Research Working Group, predecessor to Strategic Working Group under the Advisory Group on Energy
EWEA	European Wind Energy Association
FBC	Fluidised Bed Combustion
FP	Framework Programme
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GIF	Generation IV International Forum
GJ	Giga Joule
GMO	Genetically Modified Organism
GW	Giga Watt
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles
ITER	International Thermonuclear Experimental Reactor
IPHE	International Partnership for Hydrogen Economy
JET	Joint European Torus
KWh	Kilo Watt hour
LNG	Liquefied Natural Gas
LWR	Light-water Reactor
MCFC	Molten Carbonate Fuel Cell
Mt	Million Ton
Mtoe	Million Tons of Oil Equivalent
MW	Mega Watt
NGCC	Natural gas-fired combustion cycle
PAFC	Phosphoric Acid Fuel Cell
PEMFC	Proton Exchange Membrane Fuel Cell
PF	Pulverised fuel combustion
PFBC	Pressurised Fluidised Bed Combustion
PV	Photovoltaics
R&D	Research and Development
RES	Renewable Energy Sources
SMR	Steam Methane Reforming
SOFC	Solid Oxide Fuel Cell
STSS	Steam Turbine with Supercritical Steam
SWOG	Strategic Working Group under the Advisory Group on Energy
SWOT	Strengths, Weaknesses, Opportunities and Threats
TWh	Tera Watt hour

Introduction

Availability of energy is a prerequisite for economic growth and welfare in Europe and the world as such. Nowadays, we are totally dependent on an abundant and uninterrupted supply of energy for living and working. It is a key ingredient in all sectors of modern economies.

All over the world, increasing energy consumption, liberalisation of energy markets and the need to take action on climate change are producing new challenges for the energy sector. At the same time, there is increasing pressure for research, new technologies and industrial products to be socially acceptable and to generate economic wealth and quality of life. The result is a complex and dynamic set of conditions affecting decisions on investments in research and new energy technology (Larsen, 2002).

The challenge for energy research is hence to reconcile conflicting pressures and seek to address:

- Security and diversity of energy supply
- Global climate change and environmental degradation
- Economic competitiveness, and
- Social benefit.

The strategic goal of EU energy research is to develop sustainable energy systems and services for Europe. In addition, the aim is to contribute to a more sustainable development worldwide (www.europa.eu.int/comm/research/energy/). This strategy will lead to an increased security and diversity of energy supply, and will provide Europe with high-quality, low-cost energy services, improved industrial competitiveness, reduced environmental impact and a better quality of life for all Europeans.

This report on key energy technologies for Europe gives an overview of where the EU stands and a forward look over the coming years of research challenges. It is based on existing materials and literature and not on new data collection. This has presented major challenges in the assessment of the present strengths and weaknesses and in particular the assessment of future opportunities and threats. Such assessment would have benefited from a truly foresight approach, including broader stakeholder participation in the communication about the longer-term issues and the building of consensus on the most promising areas.

The outline of the report is as follows:

- In this introductory section, energy technologies are defined and for analytical reasons further narrowed down.

- The description of the socio-economic challenges facing Europe in the energy field takes its departure in the analysis made by the International Energy Agency going back to 1970 and with forecasts to 2030, including a reference and an alternative policy scenario. Both the world situation and the European situation are described. This section also contains an overview of the main EU policy responses to energy. Both EU energy R&D as well as Member State energy R&D resources are described in view of international efforts.

- The description of the science and technology base is made for selected energy technologies, including energy efficiency, biomass, hydrogen and fuel cells, photovoltaics, clean fossil fuel technologies and CO_2 capture and storage, nuclear fission and fusion. When possible a SWOT is made for each technology and finally summarised.

- Summarised SWOT of key energy technologies.

- The forward look highlights some of the key problems, questions and uncertainties related to the future energy situation. Examples of recent energy foresights are given, including national energy foresights in Sweden and the UK as well as links to a number of regional and national foresights and roadmaps.

- Appendix I contains a short description of key international organisations dealing with energy technologies and energy research.

Defining Energy Technologies

Before going into detail with the socio-economic challenges in the field and the assessment of the European science and technology base, it is worthwhile to define the technological area. Energy technologies may be defined in various ways.

A broad definition is provided by the World Energy Council (World Energy Council, 2001: 5) that includes all aspects of:

- resource extraction and production;
- power generation;
- transmission, distribution and energy storage;
- energy efficiency and conservation;
- end-use technologies;
- carbon separation, capture and sequestration.

For statistical aims, the International Energy Agency groups energy technologies in the following main groups (European Commission, 2005a: 51-53):

1. Energy efficiency
2. Fossil fuels: oil, gas and coal
3. Renewable energy sources
4. Nuclear fission and fusion
5. Other power and storage technologies
6. Other cross-cutting technologies and research

A structured definition distinguishes between end-use technologies, energy carriers and energy sources and their dynamic interplay (World Energy Council, 2004: 6). An energy carrier most often transmits energy from source to end-use and each step involves costs (energy losses and capital investment). End-uses hence include industry, households and transportation.

An environmental problem-oriented definition is provided by a study on energy technology and climate change that views the technologies from the point of view of efficient and clean technologies available for reducing greenhouse gas emissions (International Energy Agency, 2000: 31). These technologies are grouped in four categories comprising energy efficiency (in building, industry and transport), clean power generation, cross cutting technologies (such as combined power and heat, advanced gas turbines, sensors and control and power electronics) and technologies for carbon capture and sequestration (Ibid: 33-34).

A broader societal problem-oriented definition is provided by the EurEnDel project (Wehnert et al., 2004). Problem fields were identified in a cross impact analysis aiming at isolating the main drivers of Europe's future energy system including society, environment and energy systems. Those drivers that have an important impact and at the same time are under the control of European decision-makers were selected for further investigation. They comprised 19 technology trends covering:

- Energy demand (industry, housing and transport)
- Storage, distribution and grids
- Energy supply

An energy value chain definition focuses on the value added and profits in each step of the energy chain from sources to end-use. It comprises three interlinked dimensions: the upstreamdownstream vertical dimension, the hardware and software element of the horizontal dimension, and the lateral dimension associated with agriculture and chemistry (Bruggink, 2005: 57).

The definition used by this study is mainly a broad problem-oriented definition covering:

- End-use technologies and energy efficiency for industry, households and transport
- Energy carriers covering electricity, heat, liquid fuels, gases and solid fuels
- Energy sources covering fossils fuels, renewables and nuclear energy

Enabling technologies (sensors, information technologies, biotechnology, nanotechnology, smart materials) are key to developing secure, affordable and clean energy technologies. However, this study does not analyse these technologies as most of these are dealt with by other contributions to the Key Technology Study undertaken.

To some extent end-use technologies are also covered by other contributions to the Key Technology Study, including manufacturing and transport. In this report, these sectors will primarily be assessed from the point of view of energy efficiency. There is also some overlap with environmental technologies as the energy technologies address the three Es: Energy security, the environment and economic growth.

Narrowing the Analytical Scope

The definition of energy technologies is still too broad, and there is a need for narrowing the analytical scope to key energy technologies for future European research. This is done in a pragmatic way, relying on present priorities, the proposals presented by the Strategic Working Group (SWOG), the prioritisation made by the EurEnDel study and the priority energy technologies selected for the Commission study on priority energy technologies.

The energy sub-themes proposed in the Seventh Framework Programme as well as in the 7th Euratom Research Framework Programme follow extensive consultation and will be subject to final approval by the European Parliament and by the Council of Ministers (Commission of the European Communities, 2005b).

The overall objective of the non-nuclear energy R&D in the Seventh Framework Programme is to transform the current fossil-fuel based energy system into a more sustainable one based on a diverse portfolio of energy sources and carriers combined with enhanced energy efficiency, to address the pressing challenges of security of supply and climate change, whilst increasing the competitiveness of Europe's energy industries. The selected sub-themes are:

- Hydrogen and fuel cells
- Renewable electricity generation
- Renewable fuel production
- Near zero emission generation, including clean coal and CO_2 capture and storage
- Smart energy networks
- Energy savings and energy efficiency
- Knowledge for energy policy making

The objective of the 7th Euratom Research Framework Programme for fusion energy is to develop the knowledge base for, and realising ITER as the major steps towards the creation of prototype reactors for power stations which are safe, sustainable, environmentally responsible and economically viable. Sub-themes include[1]:

- The realisation of ITER
- R&D in preparation of ITER operation
- Technology activities in preparation of DEMO

[1] Excluding Infrastructures and Human resources, education and training.

- R&D activities for the longer run, including improved concepts for magnetic confinement schemes and understanding of the behaviour of fusion plasma.

The objective of the 7th Euratom Research Framework Programme for nuclear fission and radiation protection is to establish a sound scientific and technical basis for the safe management of long-lived radioactive waste, promoting safer, more resource-efficient and competitive exploitation of nuclear energy and ensuring a robust and socially acceptable system of protection of man and the environment against the effects of ionising radiation. Sub-themes include[2]:

- Management of radioactive waste
- Reactor systems
- Radiation protection

Further, the strategic vision for energy R&D on a European scale developed by the Advisory Group on Energy (AGE) emphasises that sustainable energy provision should require that energy supply is secure, affordable and clean. The only route to such a sustainable energy system is through new and better energy technologies (EU Commission, 2005c: 9). More R&D is hence needed in a portfolio of energy technologies and options, which should focus on R&D "Schwerpunkte". Such focal R&D areas were first suggested in 2001 by the EU 'Energy Research Working Group' (EWOG), comprising Improved energy efficiency, Renewable energy sources, Cleaner use of coal and other fossil fuels, Nuclear fission and fusion energy and Hydrogen as an energy carrier. Within these broad groups considered by EWOG, the Strategic Working Group (SWOG)[3] identified the following key technologies, which have also been endorsed by AGE:

- Biomass
- Cleaner use of coal
- Fuel cells
- Hydrogen as an energy carrier
- Nuclear fission
- Nuclear fusion
- Solar photovoltaics
- Wind energy

The EurEnDel project is the first European-wide Delphi study on future developments in the energy sector (Wehnert et al., 2004). All technologies will play an important role in the future European energy system, but some technologies are high-priority, while other technologies are important under certain conditions. Not surprisingly, the technologies with a mid-term and long-term perspective need more R&D than those with a short-term perspective – here other mechanisms are needed such as fiscal measures and regulations etc. In short, technologies with a need for basic and applied R&D include biomass, energy efficiency, ocean technologies, fuel cells, biofuels, energy storage and distribution, nuclear fission, super conductive materials, CO_2 capture and storage, photovoltaics, nuclear fusion and hydrogen.

A study commissioned by the European Commission on priority energy technologies includes (Jitex, 2004[4]):

- Photovoltaics
- Biomass
- Fuel cells (stationary and transportation)
- Hydrogen technologies (production, storage and utilisation)
- Fossil fuel technologies (centralised and distributed power production technologies)

---

[2] Excluding Infrastructures and Human resources, education and training.

[3] SWOG was established by AGE to provide guidance on energy research priorities and strategies, at EU and Member States level.

[4] This draft report has later been published by the EU Commission. Strengths Weaknesses, Opportunities and Threats in Energy Research. 2005.

- CO_2 capture and storage

In conclusion, the selection of key energy technologies for this report is presented in the table below. The exclusion of for example wind technology, concentrated solar thermal energy and ocean technology does not imply that these technologies should not be considered as future key energy technologies. The selection of technologies for further description does not reflect any prioritisation, but due to the lack of a European energy technology foresight the identification of key energy technologies is done in a pragmatic way, using available studies and priorities.

Table 1. Overview of key technologies by different sources, including this study.

FP7	**SWOG**	**EurEnDel**	**Jitex**	**Key Energy Technologies**
Hydrogen and fuel cells	Hydrogen as an energy carrier Fuel cells	Fuel cells for transport Hydrogen production and storage	Fuel cells Hydrogen technologies	Hydrogen and fuel cells
		Energy storage technologies and distribution Super-conductive materials		
Renewable electricity generation	Photovoltaics Wind energy	Photovoltaics Ocean technologies	Photovoltaics	Photovoltaics
Renewable fuel production	Biomass	Biomass Biofuels	Biomass	Biomass and biofuels
Near zero emission generation, including clean coal and CO_2 capture and storage	Cleaner use of coal	CO_2 capture and storage	CO_2 capture and storage Fossil fuel technologies	Fossil fuel technologies CO_2 capture and storage
Smart energy networks				End-use technologies and energy efficiency
Energy savings and energy efficiency		Energy efficient technologies		
Nuclear fusion	Nuclear fusion	Plasma confinement		Nuclear fusion
Nuclear fission	Nuclear fission	Safe nuclear fission		Nuclear fission

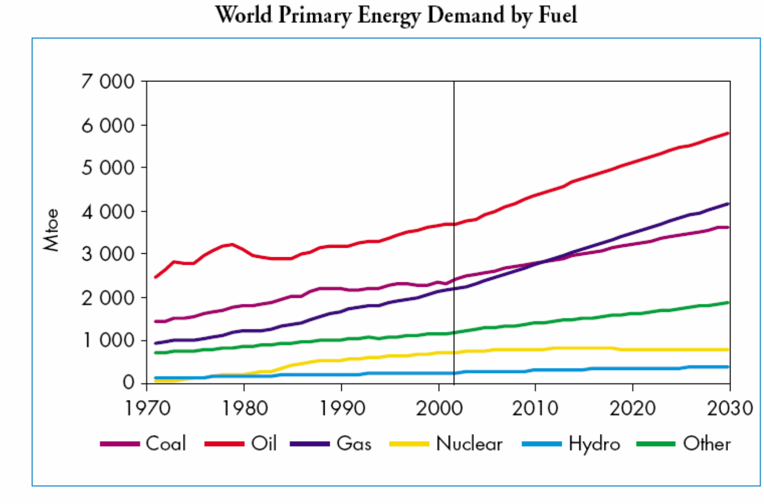
The Socio-economic Challenges for Europe in Energy

Global Energy Perspectives and Challenges

The world's energy system is based mainly on oil, gas and coal delivering around 80 % of the primary energy supply while 12 % is biomass and waste, 7 % is nuclear power, 2 % is hydropower and only around 0.5 % comes from other renewable energy sources such as wind, solar and geothermal power (International Energy Agency, 2004). The energy system experienced some changes after the oil crises in the 1970s. Natural gas increased its market share, and energy is generally used more efficiently both in generation and in end-use applications while environmental technology has been adapted for cleaning exhaust gases from fossil fuel burning processes. The generating capacity of nuclear reactors and renewable generators (excluding hydro) has grown by factors of 23 and 13 respectively.

Governmental bodies such as the Energy Information Administration (2004), the International Energy Agency (2004), the International Panel on Climate Change (2000), the European Commission (2003a, 2003b), associations such as the World Energy Council (2004) and the Association for the Study of Peak Oil&Gas (www.peakoil.net) and energy companies such as Shell (2004) and Exxon Mobile (2004) publish forecasts of future developments in the energy sector. Although there are differences between expectations regarding the mix of different primary energy sources and the timeline for global oil peak in these forecasts, the overall picture of a future energy system with growing energy needs being supplied mainly by oil, gas and coal remains, at least for several more decades.

The International Energy Agency forecasts the consumption of primary energy to grow by more than 60 % in the period between 2002 and 2030, with fossil fuels accounting for some 85 % of the increase and two thirds of the increase occurring in developing countries. Oil is projected to remain the largest primary fuel type whereas natural gas is projected to overtake coal as the world's second-largest primary energy source. China and India alone are projected to account for more than two thirds of the increase in global coal use (International Energy Agency, 2004: 57-80). There will be a clear differentiation in energy demand and supply growth between industrialised and developing countries and thereby also in how to deal with a number of significant problems: the need for industrialised countries to substitute present supply technologies with more efficient and clean ones and the challenge for developing countries to expand the energy supply to assure economic growth and providing access to energy sources for a vast population (Halsnæs & Christensen, 2002).



Source: International Energy Agency, 2004: 60.

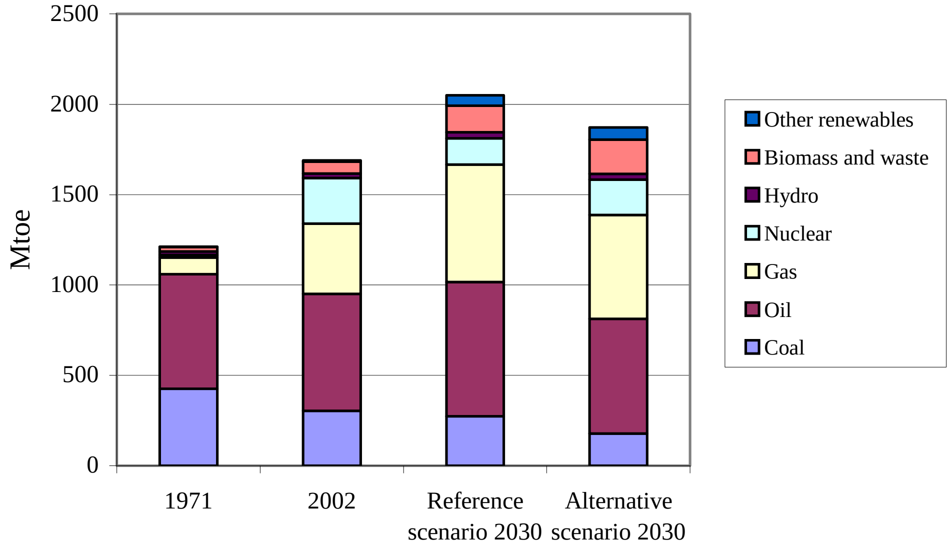
The International Energy Agency forecasts a 60 % increase in global emissions of CO_2 by 2030, and the global demand for oil and gas is expected to rise by factors of 1.6 and 1.9 respectively, while it is envisaged that consuming countries will become increasingly dependent upon energy imports (International Energy Agency, 2004: 70-72).

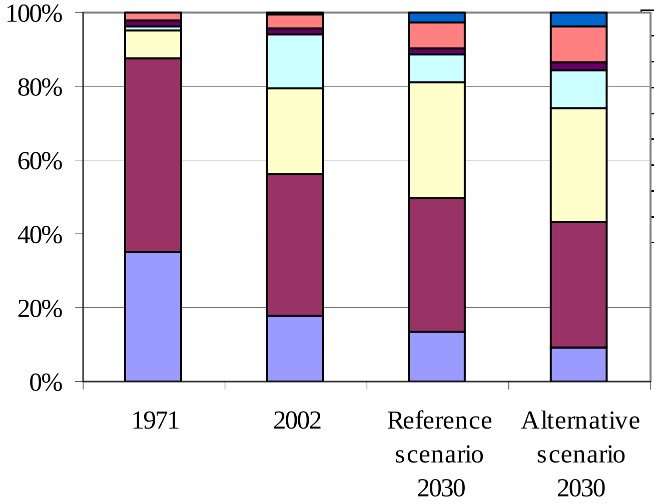
The IEA reference scenario is not trying to predict how the energy system will develop in the future. The purpose is rather to demonstrate what is likely to happen on the basis that current policies are retained. But this reference scenario is not unalterable and more vigorous government actions are presented in an alternative policy scenario in which energy demand in 2030 is some 11 % lower than in the reference scenario and the reduction in demand for fossil fuels is even more pronounced, due mainly to policies that promote renewable energy. The alternative policy scenario introduces stronger measures to improve fuel economy of vehicles leading to a lower demand for oil. Overall CO_2 emissions are reduced by 16 % over the reference scenario and almost 60 % of this reduction stems from more efficient use of energy in end-use applications (International Energy Agency, 2004: 367-427).

In conclusion, the main long-term challenges for the energy system are the increasing environmental load due to burning fossil fuels (Intergovernmental Panel on Climate Change, 2000) as well as uncertainty about continued access to cheap oil and natural gas (Longwell, 2002) and continued restricted access to modern energy services for the world's poorest people (International Energy Agency, 2004).

Outlook for Energy Use in the European Union (EU-25)

In the International Energy Agency's reference scenario for the EU-25, the primary energy demand in Europe is expected to grow by 21 % overall and 0.7 % per year over 2002-2030. There will be a marked shift in the primary fuel mix. The share of coal in the total primary energy is projected to decrease from 18 % in 2002 to 13 % in 2030. Also the share of nuclear power is expected to decrease, from 15 % in 2002 to 7 % in 2030. The share of gas increases, from 23 % in 2002 to 32 % in 2030. Likewise, non-hydro renewables increase, from 4 % in 2002 to 10 % in 2030. Projected developments in primary energy demand in the IEA's reference and alternative policy scenarios for the European Union are illustrated in the figure below.





Annual rate of growth 2002-2030	
Other renewables	7.2 %
Biomass and waste	3.0 %
Hydro	0.8 %
Nuclear	-1.9 %
Gas	1,.8 %
Oil	0.5 %
Coal	-0.4 %
Total	0.7 %

Figure 1: Overview of primary energy consumption in the EU-25 in IEA reference and alternative scenarios for 2030. Source: IEA, 2004.

The EU's imports of fossil fuels are expected to increase substantially. In 2002, 76 % of the EU's primary oil demand was imported, and this share is projected to grow to 94 % by 2030 as oil production is already in long-term decline in the North Sea where most of the EU's oil reserves are located (International Energy Agency, 2004: 107). Total EU oil production is projected to fall from 3.2 million barrels per day in 2002 to 1 million barrels per day in 2030. Also, the gap between gas production and demand will continue to widen. This implies an increase in EU gas imports from 49 % in 2002 to 81 % of consumption in 2030. A growing share of EU gas imports is projected to be shipped as liquefied natural gas (LNG) coming from reserves that can be located further away from traditional markets such as in Qatar which holds vast gas resources (International Energy Agency, 2004: 136).

In the IEA's reference scenario, energy-related CO_2 emissions rise as fast as primary energy demand in the EU and by 2030, emissions are 20 % above the 2002 level or some 4,488 Mt. Power generation remains the biggest single CO_2-emitting sector in 2030, emitting 37 %, while the transport sector contributes with 28 %. This implies that compliance with the Kyoto Protocol to cut greenhouse gas emissions to 8 % below their 1990 level in the period 2008-2012 can only be fulfilled by buying emission credits from non-EU countries.

In the alternative policy scenario, the primary energy demand in the EU reaches 1,870 Mtoe in 2030, about 9 % lower than the reference scenario. By 2030 the fuel mix is somewhat different from the reference scenario. Fossil fuels contribute 74 % of primary energy demand, compared with 81 % in the reference scenario. Coal consumption falls most. Renewables are 16 % and nuclear 10 %. Oil savings are expected to be bigger than in other OECD countries, reflecting policies to promote fuel efficiency, biofuels and mass transit. The demand for oil is cut by more than 14 % compared with the reference scenario due to a combination of policies to reach the EU's Kyoto commitment. A number of new measures in promoting renewables in power generation, in the transport sector and in buildings are included in the alternative scenario. Also the emission-trading scheme is included, which allows European companies to trade emission allowances. CO_2 emissions are expected to peak at around 3,900 Mt in 2020 and then start to fall so that by 2030, they will be 850 Mt, or 19 % lower than the reference scenario and still CO_2 emissions are only reduced by 2 % in 2030 compared to 2002 (International Energy Agency, 2004: 367-427).

In *conclusion*, the outlook for future energy use in the European Union poses some serious challenges to be overcome, especially considering the fulfilment of political goals of reducing emissions of CO_2 and reducing dependency on imported fossil fuels.

EU Policy Responses

The future of Europe depends on the energy supply being safe, sustainable and affordable. It is a matter of linking the security of supply to a sustainable development, the developments on the energy markets and the socio-economic situation in the EU. European energy policy aims at:

- reconciling energy security,
- reduced environmental impacts of energy production and use, and
- competitive economic growth.

Key energy policy actions in the European Union include:

Energy supply. The prime aim of the EU's energy policy was set out in the 2001 Green Paper on the security of energy supply, which emphasises that supply of energy is to be ensured to all consumers at affordable prices while respecting the environment and promoting healthy competition on the European energy market. The Green Paper sketches out a long-term energy strategy, according to which:

"*The Union must rebalance its supply policy by clear action in favour of a demand policy. The margins for manoeuvre for any increase in Community supply are weak in view of its requirements, while the scope for action to address demand appears more promising.*

With regard to demand, the Green Paper is calling for a real change in consumer behaviour. It highlights the value of taxation measures to steer demand towards better-controlled consumption which is more respectful of the environment. Taxation or parafiscal levies are advocated with a view to penalising the harmful environmental impact of energies. The transport and construction industries will have to apply an active energy savings policy and diversification in favour of non-polluting energy.

With regard to supply, priority must be given to the fight against global warming. The development of new and renewable energies (including biofuels) is the key to change. Doubling their share in the energy supply quota from 6 to 12 % and raising their part in electricity" (European Commission, 2001a: 4).

On the basis of the Green Paper the Commission has launched a number of new legal instruments most of which have been adopted[5].

[5] Directive on the promotion of electricity produced from renewable energy sources (2001/77/EC – OJ L283/33 – 27.10.2001); Directive on the promotion of biofuels (2003/30/EC – OJ L123/42 – 17.5.2003); Directive on energy performance of buildings (2002/91/EC – OJ L1/65 – 4.1.2003); Directive on the promotion of cogeneration (2004/8/EC – OJ L52/50 – 21.2.2004); Directive for the taxation

The liberalised energy market. Common rules have been adopted for electricity and gas respectively to ensure the free movement of electricity and gas within the Community. For major consumers, electricity and gas markets were opened up in 1999 and 2000, though the liberalisation of markets varies between Member States. In March 2001, the EU Commission adopted a set of measures to open the gas and electricity markets up fully by 2007. New electricity and gas directives were due to be transposed by Member States by July 2004, and the Regulation on cross border electricity exchanges also came into effect. The new rules are aimed at achieving competitive electricity and gas sectors across the whole of the European Union. Although many measures have been taken, various obstacles remain to be solved in many Member States to promote competition in electricity and gas markets. Some of the key concerns are the possibility of customers switching supplier, fair access to distribution and transmission grids and competitive market structures and pricing mechanisms (European Commission, 2005d).

Trans-European Energy Networks. The completion of the internal market for energy is accompanied by measures to strengthen the Trans-European Energy Networks. Currently, about one-quarter of European energy consumption is based on natural gas. According to the forecasts described above, the gas demand in the EU will increase significantly by 2030, and meeting this demand will require significant increases in gas import capacity. Electricity generation on the other hand has to be precisely matched with demand at any given time, and transmission capacity must be sufficient for peak demand to avoid the risk of blackouts. A single European energy market requires the trade of energy across national borders. The Trans-European Energy Networks programme identifies the missing links and the bottlenecks in the network and identifies priority routes in need of upgrading. The programme points at the need to invest 28 billion € for the priority energy network projects to be constructed in the 2007-13 period (European Commission, 2004d). The need for coupling wind-generated electricity to the high-voltage network requires significant upgrading of the electricity grid on a European scale, which could be coordinated by the TEN-E policy.

Climate Change. The European Union has signed the 1997 Kyoto Protocol to the UN Framework Convention on Climate Change with the goal of reducing EU-15 greenhouse gas emissions by 8 % by 2012 as compared to 1990[6], and the new EU Member States have similarly committed themselves to reducing their emissions (European Environmental Agency, 2004). The Commission's general approach has been to shape a policy framework to reinforce measures being taken at national level. These "common and coordinated" policies are, for example, voluntary environmental agreements and the promotion of the Flexible Mechanisms of the Kyoto Protocol for emission trading and project-related emission reduction (International Emission Trading, Joint Implementation, and Clean Development Mechanism). By 2002, greenhouse gas emissions by the EU-15 were down 2.9 % relative to the base-year level, taking the EU-15 little more than a third of the way towards its greenhouse gas emission target under the Kyoto Protocol of an 8 % reduction. The new Member States were down about 33 % relative to the base-year level (European Environment Agency, 2004). Therefore, additional measures are needed to meet requirements as it is also pointed out in the IEA alternative policy scenario.

Energy from renewable energy sources (RES) is key to the diversification and sustainability of the energy system. The 1997 White Paper provided a strategy and a Community Action Plan for RES in the European Union. The objective set out in the White Paper is to increase the propor-

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of energy products and electricity (2003/96/EC – OJ L283/51 – 31.10.2003); Directive on energy efficiency requirements for ballasts for fluorescent lighting (2000/55/EC – OJ L279/33 – 01.11.2000); Directives on labelling of electric ovens, of airconditioners and of refrigerators (2002/40/EC – OJ L283/45 – 15.5.2002) (2002/31/EC – OJ L86/26 – 3.4.2003) (2003/66/EC – OJ L170/10 – 9.7.2003); Regulation on Energy Star labelling for office equipment (2001/2422/EC – OJ L332/1 –15.12.2001); Directive on Eco design requirements for energy using products (Proposal COM(2003) 453); Directive on energy efficiency and energy services (Proposal COM(2003) 739).

[6] Council Decision on the Approval of the Kyoto Protocol OJ L130 of 15 May 2002.

tion of RES in the EU-15's gross domestic energy consumption for heating, electricity and transport from 6 % in 1997 to 12 % in 2010. The Commission has therefore set out the goals of increasing the share of renewables in the production of heat and electricity and for use of biofuels in the transport sector (European Commission, 2004f). The target for a 12 % share of renewable energy in overall energy consumption is an EU-15 target, but the specific targets for use of renewables in electricity generation and transport also apply to the new EU Member States. If present trends continue in heating, and if the EU-15 Member States implement the national plans they have put in place in electricity and fulfil the requirements of the biofuels directive in transport, the share will reach 9 % in 2010. In addition, if Member States fulfil the requirements of the directive on electricity from renewable energy sources, the share will reach 10 %. Fulfilment of the 12 % target for 2010 will require a steep change in national policies towards the use of renewable energy in heating (European Commission, 2004e: 33).

Electricity from renewable energy sources. A Council and Parliament directive on the promotion of electricity from renewable energy sources was adopted in September 2001 aiming at increasing the percentage of electricity from RES from 14 % in 1997 to 22 % in 2010 for the EU-15 (European Commission, 2004b). By 2003 renewables contributed almost 15 % of gross electric consumption in the EU-15 (EuroObserv'er, 2004). The EU-15 22 % target has later been revised to 21 % for the EU-25 (European Commission, 2004b). By 2001, the contribution of green electricity in the EU-25 was 15.2 % (European Commission, 2004b).

The figure below illustrates the share of renewable energy in gross electricity consumption of the EU-15 in 2003 and objectives for the EU-25 by 2010. On the basis of current trends, it is likely that around 18 to 19 % of total electricity consumption in 2010 will be produced from renewable energy sources so Member States may have to make additional efforts to meet their targets. An assessment carried out by the European Commission shows that the main reason why the target has not been achieved is that the production of electricity from biomass has not been as high as initially forecast (European Commission, 2004f).

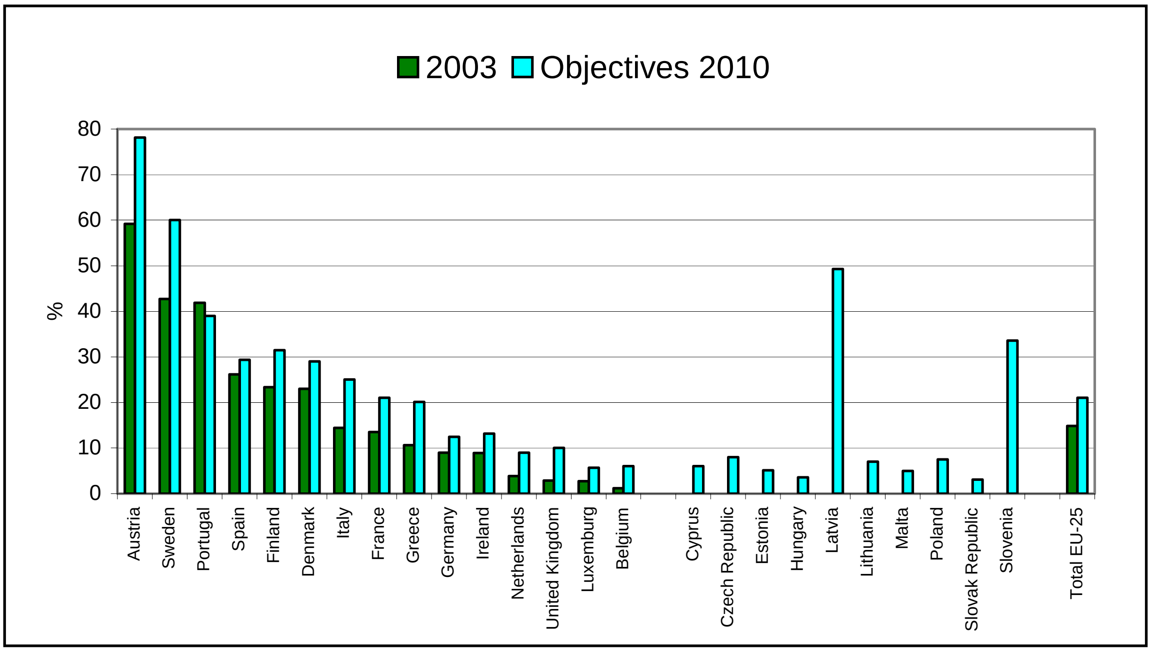


Figure 2: Share of renewable energies in gross electricity consumption of European Union countries in 2003 and targets for 2010. Source: EuroObserv'er, 2004.

The *European Transport Policy for 2010: time to decide* White Paper was adopted in September 2001 by the Commission. Around one fifth of gross primary energy consumption, or about one third of the final energy consumption, is consumed in the transport sector. Oil represents 98 % of the energy consumed in the transport sector, emitting 28 % of the CO_2 emissions. Two directives focus on the use of alternative fuels in the transport sector. The first directive provides for fuels to contain a percentage of biofuels from 2005, and the second directive allows for applying a reduced excise duty on biofuels. The targets for biofuel penetration in the EU transport fuel market are 2 % by 2005 and 5.75 % by 2010, compared with 0.6 % in 2002. Furthermore, the Commission has negotiated a voluntary agreement with the car industry aiming at reducing specific emissions of CO_2 from new passenger cars (European Commission, 2001b). However, these initiatives are not believed to be sufficient to keep pace with the growth in transport demand, and CO_2 emissions from the transport sector are therefore projected to increase (European Commission, 2001a: 16).

Energy efficiency legislation. One of the main messages of the European Commission's Green Paper on security of energy supply is that the future European energy policy should focus more on demand policies and energy efficiency (European Commission, 2001a). The European Commission estimates that directives on energy saving in buildings, combined heat and power, ballasts, refrigerator, oven and conditioner labelling and the energy star regulation may bring about energy savings in the order of 22 Mtoe by 2010, reducing total projected primary energy consumption to 1556 Mtoe (European Commission, 2004e). This compares to a consumption of 1436 Mtoe in 1998 (European Commission 2001a: 22). So the energy efficiency legislation mentioned here is not considered sufficient to reduce or even stabilise final energy consumption in the next decades. A Commission green paper on energy efficiency was published in June 2005 highlighting the need for more R&D in this field (COM(2005) 265 final).

Community support programmes. The European Commission has launched various Community support programmes to address energy efficiency and renewable energies. The multi-annual programme Intelligent Energy – Europe (EIE) adopted in June 2003 builds on the success of the Save and Altener programmes, which have supported actions in the fields of energy efficiency and renewable energy since the early 1990s. The combined budget for both previous programmes in the 1993-2002 decade was 220 million €, while the budget allocated to the new programme for the period 2003-2006 is 250 million €.

EIE is intended to improve energy efficiency (Save actions), to promote new and renewable energy sources (Altener actions), to support initiatives tackling the energy aspects of transport (Steer) and to promote renewable energy and energy efficiency in developing countries (Coopener) (European Commission, 2004e).

Economic growth. In 2000, the European Council of Ministers adopted the Lisbon agreement to be the most competitive knowledge-based area by 2010. This was later concretised in the Barcelona declaration, which set out the target of allocating at least 3 % of GDP to R&D by 2010 (1 % of GDP should be public R&D funds).

A Quick-start Growth Initiative was announced by EU President Romano Prodi in November 2003 to realise the Trans-European Energy Networks priority projects (European Commission, 2003c). These include 7 energy networks, 3 natural gas networks and 2 hydrogen projects to be realised within the next 10 years. The indicative financial resources needed are 12.433 billion € coming from EU, national, regional and private sources.

New energy technologies may become a catalyst for bringing about new industries, providing jobs in the European Community. A good example is the European wind power industry that currently produces most of the global wind turbine installations. The European wind energy sector has created more than 72,000 jobs in Europe (European Wind Energy Association). Looking forward, EWEA envisages that it may be possible to generate 12 % of the world's electricity from wind power by 2020, thereby reaching almost 200,000 employees by 2020 (European Wind Energy Association, 2004a and 2004b). However, the impact of energy R&D is not assessed systematically for key energy technologies, but some preparatory work has been done on indicators and benchmarks in order to make well-founded evaluations and assessments of the economic and societal return on R&D investments (European Commission, 2005e).

To conclude on policy responses, the EU has indeed outlined the long-term challenges involved in providing an affordable, sustainable and efficient energy supply. The electricity and gas markets are liberalised, and this is further accompanied by the need to invest in priority international energy network projects. The EU has ratified the Kyoto Protocol with the goal of reducing GHG emissions by 8 % by 2012, and recently the European environmental ministers recommended new ambitious targets for medium and longer-term reduction beyond 2012. Ambitious targets are set for the share of renewable energy resources (12 % by 2010) as well as for electricity from renewables (21 % by 2010). In the transport sector, targets for biofuels are set to 2 % of the fuel market by 2005 and 5.75 % by 2010. Also as regards energy efficiency, energy savings are foreseen in the order of 22 Mtoe by 2010. The Barcelona targets of increasing the overall R&D budget also relates to energy technologies.

However, the implementation of these policies and targets poses serious problems and in the end depends on the fulfilment of each Member State. Obstacles remain to promote competition in the gas and electricity markets in the Member States, including the necessary financial commitment to priority energy networks. The EU Member States have serious problems meeting the Kyoto GHG reductions, and additional measures are required to meet the requirements. The fulfilment of targets for renewable energy sources and electricity from renewables will require additional efforts by the EU. Even if the targets for biofuel are fulfilled, further initiatives are needed to address the growth in the demand for transport. Action has been taken to address economic growth by the so-called Quick-start Growth initiative with a number of resource-demanding infrastructure projects to be realised within the next 10 years, but financial commitment from the EU, Member States and the private sector is still to be demonstrated. Last but not least, R&D resources for energy technologies have declined. This will be further analysed below.

European Energy R&D Policy

As there is still no internal market for European energy R&D, the description of European energy R&D is split into a description of EU energy R&D and Member States energy R&D.

EU Energy R&D

Alongside the legislative and other measures described above, the Commission has supported research, development and demonstration projects in the field of non-nuclear energy under the ENERGY Programme of the Framework Programmes. As regards nuclear energy, this area is the responsibility of the European Atomic Energy Community (EURATOM) set up in 1957. EURATOM has a number of tasks including R&D into the peaceful use of nuclear energy.

In the table below, total expenditure for energy R&D in the Framework Programmes is shown. Energy R&D expenditure has decreased over the years in real terms, and the percentage of total Community R&D has dropped from 66 % to only 12 % of the EU Framework Programme expenditure.

Table 2. Overview of Energy Funds in the Framework Programmes.

	Total R&D billion €	Energy R&D billion €	Energy R&D (% of total R&D)	Nuclear energy R&D (% of total R&D)	Non-nuclear energy R&D (% of total R&D)
Before FP			66		
FP1 – 1983 to 1986	3.8	2.508	66	??	??
FP2 – 1987 to 1990	5.4	2.700	50	??	??
FP3 – 1991 to 1994	6.6	1.506	23	??	??
FP4 – 1995 to 1998	13.2	2.412*	18	10	8
FP5 – 1999 to 2002	14.9	2.303*	15	8	7
FP6 – 2003 to 2006	17.5	2.040*	12	7	5

Source: EU Commission, 2005c: 19; * Froggatt, A., 2004: 14.

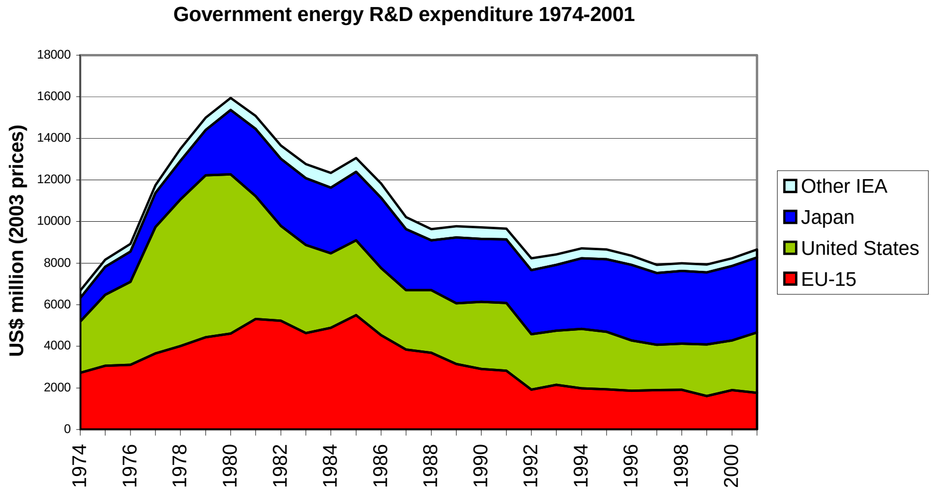
Originally, nuclear R&D was the prime focus of the European Community in the framework of the Euratom Treaty of 1957. This field of research has over the years received approx. 1 billion € per FP, but the share has decreased over the years. Non-nuclear energy R&D has been subject to substantial fluctuations. Renewable energy R&D has steadily gained importance, building upon the success in wind technology and the increasing influence of the European Parliament. Renewable energy-related R&D represents around half of the non-nuclear energy budget since 1994 (World Energy Council, 2001: 100-101).

Member States' Energy R&D

Compared to other countries, the energy R&D investments at EU Member State level have likewise decreased over the years, and this reduction rate has been higher for EU Member States than for other IEA countries (see figure below)[7].

[7] Data on energy research expenditures under the successive EU Framework Programmes are not included in the IEA statistics. The lack of EU data means that IEA statistics can at best provide only a limited view of the R&D funding landscape in Europe and in specific technology areas (European Commission, 2005a).

While the USA and the EU-15 have scaled down government investments in energy R&D, Japan tripled funding for energy R&D in the late 1970s and has kept on investing rather steadily since then. The EU-15 has cut funding by around 35 % since the early 1970s or 68 % since the peak year 1986. Japan now spends over 40 % of the total government-funded energy R&D budget of the IEA countries while the USA and the EU-15 spend about 33 % and 20 % respectively (see figure below).



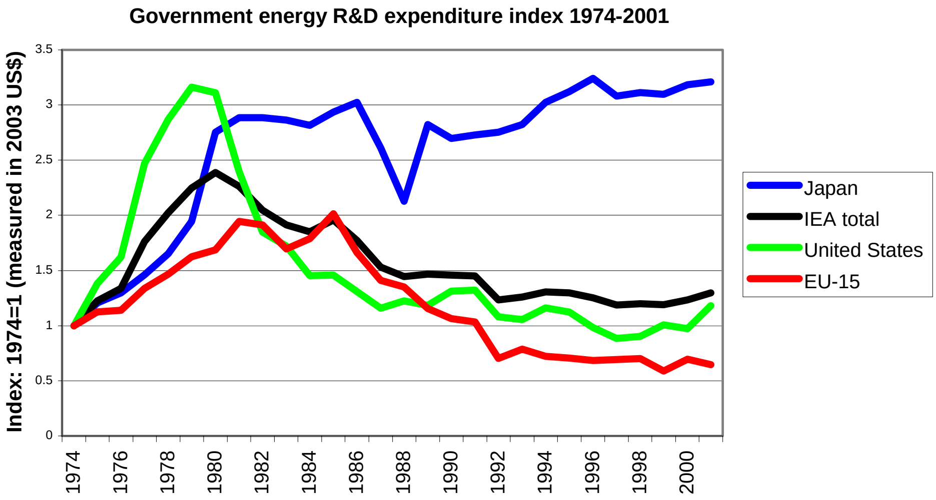


Figure 3: Government energy R&D expenditure of IEA countries 1974-2001. Source: International Energy Agency R&D Statistical website: http://www.iea.org/rdd/eng/.

Over the period 1974-2002, 58 % of government energy R&D funding in the IEA countries has been directed at nuclear fusion and fission, 13 % has been spent on fossil fuels, 8 % on conservation, 8 % on renewable energy, 3 % on power and storage technologies and 10 % on other types of energy research. In 2002, the funds for nuclear fusion and fission dropped to 39 %, 9 % was spent on fossil fuels, 18 % on conservation, 9 % on renewable energy, 7 % on power and storage technologies and 18 % on other types of energy research.

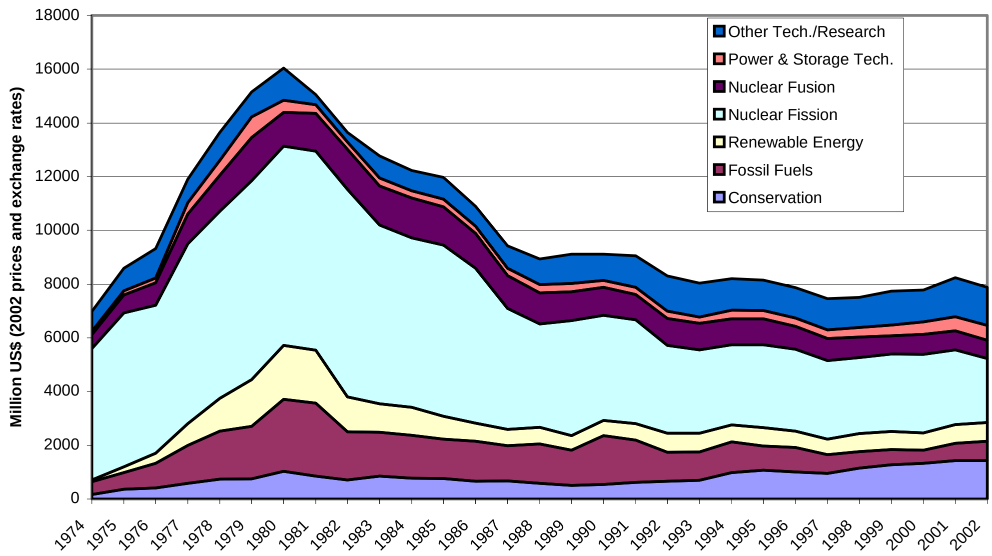


Figure 4: Breakdown of government energy R&D expenditure on different research areas 1974-2002. Source: International Energy Agency R&D Statistical website: http://www.iea.org/rdd/eng/.

While Europe and especially Japan continue investing a rather large share of total funds in nuclear research (46 % and 70 % respectively), the USA has shifted focus towards other areas throughout the last decade spending only 11 % on nuclear energy. The USA spends almost four times as much on conservation as the EU-15 and five times as much as Japan. The EU-15 only spends around 13 % of energy R&D on conservation and 17 % on renewable energy. But the EU-15 spends 15 % more on renewable energy than the USA and more than twice as much as Japan. In the overall budget for energy R&D, the USA and Japan spend 1.6 and 2 times as much as the EU-15 (see figure below).

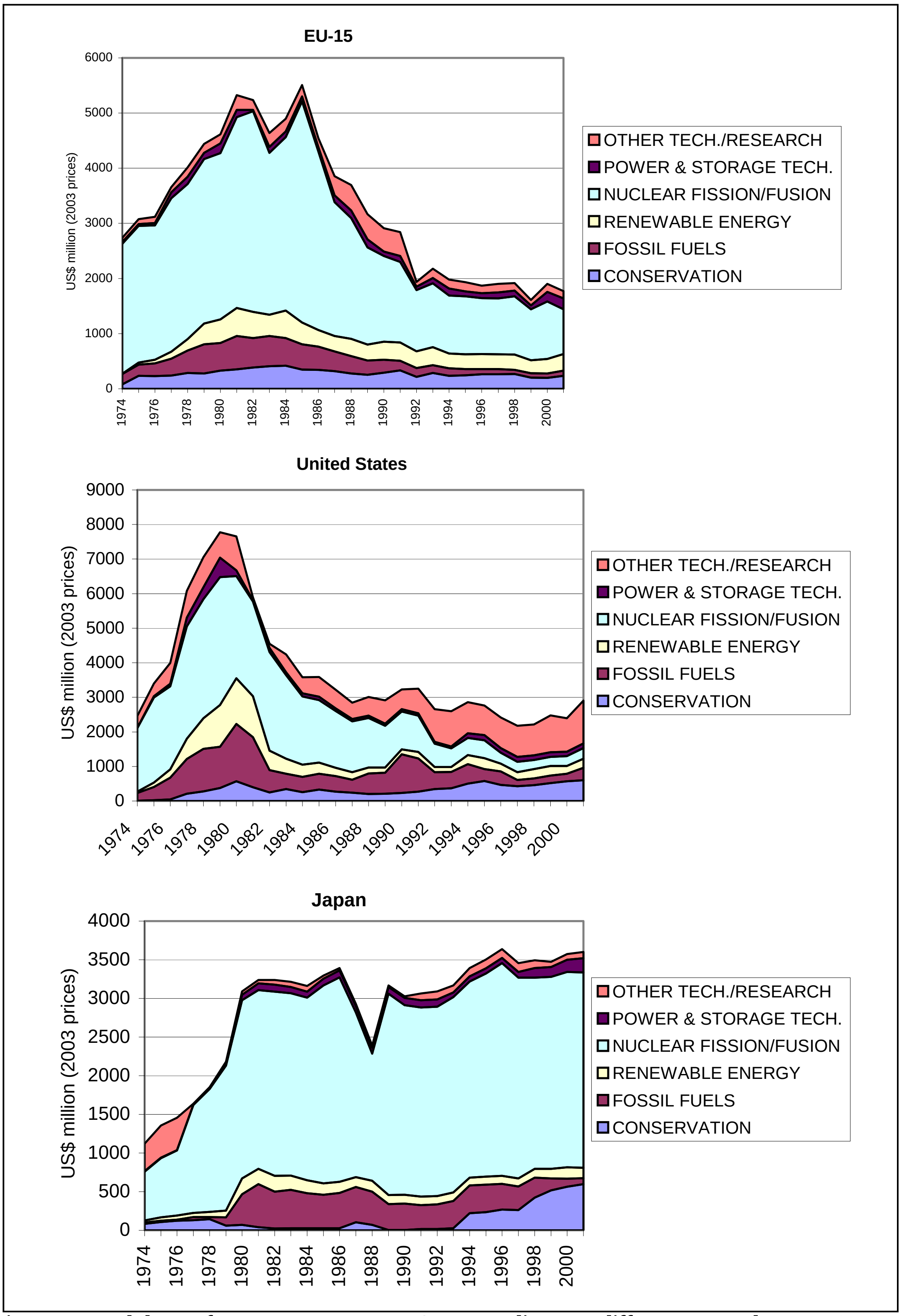


Figure 5: Breakdown of government energy R&D expenditure on different research areas 1974-2002 in the EU-15, the United States and Japan. Source: International Energy Agency R&D Statistical website: http://www.iea.org/rdd/eng/.

In a recent assessment of funding for renewable energy R&D from governments, the private sector and the EU, the European Commission concludes that around half the spending on renewable energy research in the EU comes from the public sector. In 2001, total government expenditure was in the order of 350 million €, some 340 million € came from other sectors and EU contributed an additional 90 million € (European Commission, 2004h: 13). One third of the EU-15 government research spending and half of the personnel working on research into renewables are from Germany. Denmark and the Netherlands have the highest ratio of research spending on renewables compared to total national R&D expenditure – about 0.7 % of total R&D national expenditure. Further, Denmark, Finland, the Netherlands and Sweden have a leading position in renewables energy R&D with 0.018-0.014 % of GNP (Ibid: 8).

There is a marked distinction between, on the one hand, the EU-15 Member States and most of the Associated countries and, on the other hand, the new Member States in the area of non-nuclear energy R&D programmes (European Commission, 2005h). The latter group did not have any form of dedicated non-nuclear R&D programmes by the end of 2003. And the first group of Member States has considerable thematic variety, except for some emerging priorities between Member States on power and storage technologies, in particular fuel cells and PVs and to a lesser extent on biomass and conservation (European Commission, 2005h). In particular, the challenge for the new Member States is enormous to catch up with the other member States in energy R&D. Most new Member States have well-trained energy researcher populations, but often weakly developed energy policies and weakly developed R&D infrastructures.

To conclude both the EU and Member States have cut energy R&D funds over the years. The FP energy funds have dropped in real terms and seen a dramatic cut from 66 % of total FP resources in FP1 to 12 % in FP6. Nuclear energy R&D remains stable in real terms but its share of the energy R&D has dropped to 7 % in FP6. Non-nuclear research has increased over the years, with renewable energy R&D gaining in importance. In FP6, 5 % of total R&D funds were allocated to non-nuclear R&D.

At Member State level, energy R&D investments have been cut dramatically since the early 1980s. Nuclear R&D represents 46 % of the EU-15's energy R&D. The EU-15 only spends around 17 % on renewable energy, but compared to the USA and Japan, the EU-15 invests much more in this field. Renewable energy R&D is primarily performed in Germany, but priority is also given to renewable R&D by the Nordic countries and the Netherlands. In the area of non-nuclear energy R&D, despite generally well-trained energy researcher populations, the New Member States face serious challenges to catch up with the rest of the Member States in dedicated non-nuclear energy programmes.

Conclusion

Considering current trends, the outlook for the global energy system is one of a world that is dependent on fossil fuels. This is clearly not sustainable. We do not know precisely at what point in time the world's capacity for extracting fossil fuels will fall short of demand. What we do know is that it will happen at some point in time unless the world's nations develop new policies for reversing drastically the current trends in the energy and transport sectors. The 2030 forecast made by the IEA implies increasing demand, increasing dependence on imported fossil fuels and increasing GHG emissions.

The EU policy response to this situation is diversified, trying to combine market-pull measures with technology-push solutions. The European Commission's energy policy goals laid out in the Green Paper on the security of energy supply focus primarily on improving energy efficiency and on increasing the share of renewable energy sources for the purpose of ensuring energy security and reducing greenhouse gas emissions. Ambitious EU targets are set for renewable energy sources, electricity from renewables, alternative fuels in the transport sector and energy efficiency. But the implementation of the targets meets serious obstacles as they are not mandatory and thus depends on the compliance of each individual Member State. This is serious enough, but additional measures are needed to fulfil the political goals of reducing emissions of CO_2 and reducing dependency on imported fossil fuels.

The FP energy funds have seen a dramatic cut from 66 % of total FP resources in FP1 to 12 % in FP6. Although nuclear energy R&D remains stable in real terms, its share of the energy R&D has dropped to 7 % in FP6. Non-nuclear research has increased over the years, with renewable energy R&D gaining in importance.

In the period 1974-2002, the EU-15 governments have invested less than the USA in energy R&D, but more than Japan. EU-15 funds peaked in the early 1980s in the realm of the oil price shocks of the 1970s, but have been cut by two thirds since then. Today, EU-15 energy R&D investments are substantially lower than those of Japan and the USA.

Since 1974, the EU-15 has used more than two thirds of total energy R&D funds for nuclear energy, both fission and fusion, and in 2001 the figure was 46 %. This prioritisation of funds is much more than what is seen in the USA, but substantially less than in Japan. Energy efficiency makes up 13 % of the EU-15's energy R&D, but in real terms this R&D only represents 25 % of the US investments in this field. Renewable R&D makes up 17 % of funds though the effort is very unevenly distributed among the Member States with Germany as the front-runner followed by the Nordic countries and the Netherlands. At least this gives room for increased efforts from other Member States.

Table 3. SWOT of socio-economic challenges.

Strengths	Weaknesses
• Diversified policies, including market-pull and technology-push measures • Ambitious targets for RES, RES-E, bio-fuels, CO_2 reductions and energy efficiency • Infrastructure investments to sustain/support a liberalised gas and electricity market • Relatively stable R&D nuclear energy at EU and Member State levels • Increasing share of renewable energy R&D	• Though ambitious, EU targets are not radical enough given the challenges in terms of the energy supply and CO_2 e-missions. • Implementation problems • No enforcement mechanisms, except for "common and cooperation" measures • Decreasing FP energy R&D • Decreasing EU-15 energy R&D (1974-2002) • Much less EU-15 energy R&D funds than Japan and less than the USA (1974-2002). • Political awareness of energy efficiency R&D, but in practice relatively low priority compared to the USA • Unevenly distributed renewable energy R&D between Member States • Marked distinction between New Member States and the EU-15 in terms of dedicated non-nuclear energy R&D programmes
Opportunities	**Threats**
• The EU has the possibility of combining various market-pull and technology-push measures to address security of supply, climate change and environmental problems.	• Investments in energy are long-term, and the EU-25 may be too slow to address the challenges related to the growing dependence on imports of fossil fuels, climate change, environmental problems and economic growth. • In the longer term, the EU-25 may be ill-prepared for possible disruptions in fossil energy trade or possible price fluctuations, for example due to inadequate investments in fossil energy extraction capacity in countries outside the EU.

Europe's Science and Technology Base in Energy Technologies

The European science and technology base in energy technologies will be described in this section. The following technologies are described:

- End-use technologies and energy efficiency (in industry, households and transport)
- Biomass, biogas and biofuels
- Hydrogen and fuel cells
- Photovoltaic
- Fossil fuel technologies and CO_2 capture and storage
- Nuclear fission
- Nuclear fusion

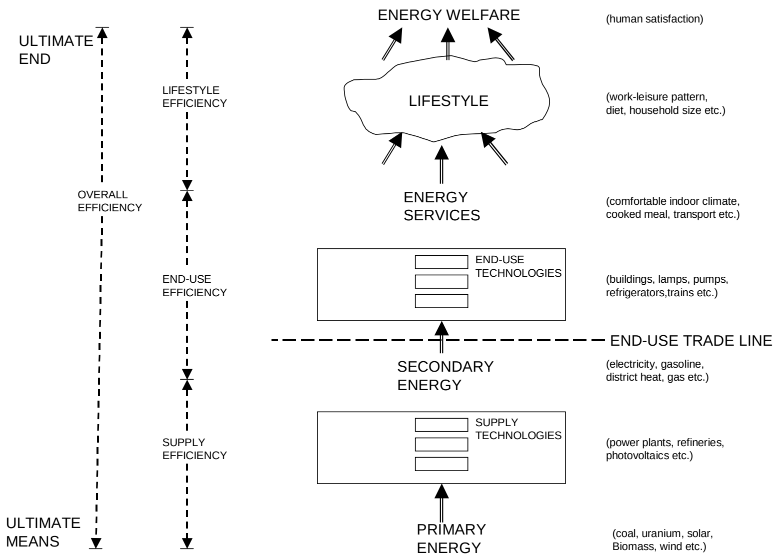
End-use Technologies and Energy Efficiency

Overview

Energy end-use technologies cover a vast and diversified area, which is closely related to energy context and country. According to the IEA reference scenario, the energy use in final sectors will grow by 1.6 % annually through to 2030, almost similar to the growth in primary energy demand (International Energy Agency, 2004: 66). Transport demand will grow by 2.1 % per year, whereas industrial and residential and service consumption will grow by 1.5 % annually.

Energy efficiency or energy conservation is seen as a promising way of achieving the goals of energy security, environmental protection and economic growth. In the EurEnDel study, energy efficiency or demand side-oriented technologies topped the rankings of the beneficial impact on wealth creation, environment, quality of life and security of supply (Wehnert et al., 2004). It is generally believed that there is a vast potential for increasing energy-efficient, but also that the future role of energy efficiency technology depends on whether efficiency improvements are translated into changing consumer behaviour with reduced energy consumption and lower emissions (International Energy Agency, 1997: 284).

Looking at the energy system as a chain of energy flows, different levels of efficiency improvements appear (Karlsson, forthcoming). At the first level, primary fuels are explored and transported and then pass through refineries and power plants converting the primary source into secondary energy in the form of electricity, fuel oil, gasoline etc. to supply the end-use technologies. At the second level, end-use technologies with certain levels of efficiency deliver the desired energy services. Next, a bundle of energy services describe a certain lifestyle contributing to human welfare. The chain illustrates that using an electrical cooker in Europe has impacts on the energy consumption and emissions all along the chain down to South Africa where the coal used in the power plants is mined.



Technology Trends
EU energy conservation and use focuses on deducing the energy intensity of demand and using energy much more efficiently. Research addresses energy conservation and use in:

- Industry – developing and demonstrating processes and process control technologies aimed at securing a reduction in energy demand in the manufacturing and agricultural sectors.

- Buildings – reducing EU energy requirements by 30 % by 2010 and 50 % in the longer term are the research aims. Currently, the built environment in the EU accounts for about 40 % of the total energy requirements.

- Transport – improving the energy and environmental performance of vehicles and the related infrastructure.

To our knowledge, there are no detailed comparative studies on energy efficiency R&D at European level. Therefore, a more general approach will be used.

Energy efficiency in industry
Industry consumes 30 % of the world's energy today. Seven energy-intensive industries account for most of the end-use demand in the IEA region: the chemical industry, aluminium production, iron and steel, pulp and paper, cement, glass and ceramics, and food processing. Likewise cross-cutting technologies are included.

The chemical industry is among the most energy-intensive industries. Many of the emerging technologies introduce improved processes that work at lower temperatures or make more effective use of catalysts.

The aluminium industry has a high power requirement for smelting and fabrication. The major application areas comprise transportation (25 %), packaging (20 %) and construction (20 %) and require a reliable electricity supply.

The steel industry is mainly located in China, Japan, the USA and Russia. It has increased productivity in the industrialised countries. In Sweden, the steel industry has undergone major structural changes, from bulk deliveries to high-priced niche products. It is based on two production processes, the iron-ore blast furnace process and the scrap iron electro-steel process.

The pulp and paper industry is an important economic sector in countries such as the USA, Canada, China, Sweden and Finland. In Sweden, it makes up about 50 % of total industrial energy consumption and about 40 % of industrial electricity consumption. Recycling paper is important from the point of view of raw material efficiency and waste management. Pulp production rests on two main processes, a chemical and a thermomechanical process. The IEA programme for energy-efficient technologies for the paper and pulp industry focuses on process integration and gasification technologies for black liquor and biomass.

The cement industry has high energy intensity and high carbon emissions. Three processes are used: wet, semi-dry and dry. Further improvements can be made through changes in product mix and measures related to raw materials preparation.

The most important areas for technology development in the industrial sector can be summarised to be (World Energy Council, 2004: 60):

- New and profitable products
- Process integration, including heat recovery and cogeneration of electricity
- Efficient use of raw materials including recycling, energy efficiency and decreased emissions
- Reducing environmental impact of both production processes and product use
- New electro-technologies including steelmaking with microwaves and ethylene production.

Energy Efficiency in Buildings
Buildings consume slightly more than 30 % of the world's energy. In the European Union (EU-15), the energy consumption for households and services makes up 25 % of the total. Included are the buildings themselves, the envelope and the appliances used as well as advanced management and communication systems. Some R&D needs over the next decades are highlighted in the table below.

Table 4. R&D needs in buildings.

	R&D needs
Envelope	• Advanced insulation technologies (in roof, walls and floor) • Advanced window technologies (windows using advanced materials with low thermal conductivity; windows with built-in solar cells) • Building materials using recyclable materials • Thermal storage materials
Equipment and appliances	• More efficient heat pumps • Micro CHP (based on fuel cells) • Alternative refrigeration means including Stirling cycles, Brayton cycles, and acoustics, magnetic and thermal-electric technologies • Low-power bulbs and hybrid lighting systems
Intelligent systems / smart buildings	• Automated diagnostics • Advanced sensors • Integrated control networks • Stand-by

Energy Efficiency in Transport
Transportation is a critical end-use sector of energy, and it currently uses about 20 % of global primary energy. Alternative fuels to gas and diesel are sought and include biofuels, compressed natural gas (CNG) and hydrogen to be used in internal combustion engines or in fuel cells. Key uncertainties are related to hydrogen and fuel cells: Will hydrogen be the dominant transport fuel sometime in the future and can fuel cells compete with the internal combustion engine? This will be dealt with under the description of these technologies.

Strengths and weaknesses for Europe
As regards science and technology, it is surprising that despite the high political awareness, only 13 % of EU-15 energy R&D is spent on this field. FP6 does give priority to reducing energy consumption, but unlike the other priorities examples of supported projects are not presented on the webpage (http://europa.eu.int/comm/research/energy/nn/nn_rt/article_1075_en.htm#5, 24 March 2005). In conclusion, there is a positive attitude towards energy efficiency R&D, but this has not so far transformed into a coherent and highly profiled research area at EU level. It is also significant that neither SWOG's key tasks for future European energy R&D nor the Commission's priority energy technologies address energy efficiency technologies.

Instead, most EU *policies* have focused on market-pull initiatives. These include support programmes such as the Intelligent Energy Europe programme (2003-2006) with support for non-technological actions. The Save programme also promotes energy efficiency and encourages energy-saving behaviour in the various sectors. Actions include legislation, such as the proposal for promotion of end-use efficiency and energy services, the directive on the promotion of co-generation (in force), the directive on energy performance of buildings (in force) and a range of legislative measures for EU labelling schemes and minimum efficiency requirements in the domestic sector (in force). Actions also include voluntary agreements with the car industry to reduce CO_2 emissions from new cars (see also page 16). Lastly, a series of promotional initiatives on energy efficiency for office equipment, motor-driven systems and lighting have been introduced as well as a public awareness campaign for an energy-sustainable Europe (2004-2007).

In *conclusion*, a lot of opportunities relate to energy efficiency R&D, but compared to the USA, Europe invests relatively little in this field. Most efforts have been dedicated to market-pull initiatives, and this can be further complemented by technology-push R&D and thereby make use of the full potential of measures to promote energy efficiency and use.

Biomass, Biogas and Biofuels

Overview

Today, biogas, biofuels, solid biomass and waste supply less than 4 % of the EU-25's primary energy demand (International Energy Agency, 2004: 466). Biomaterials and waste are used for producing solid, liquid and gaseous fuels that are used in transport, electricity generation and heating applications.

Targets for the increased use of biomass and biofuels in the generation of electricity and heat as well as in the transport sector are important elements in the European Union's overall objective of increasing the share of renewables to supply 12 % of primary energy demand in the EU-15 by 2010. Biofuels are targeted to supply 2 % of the fuel consumed in the transport sector by 2005 and 5.75 % by 2010. Biomass is envisaged to play a major role in heating by delivering more than 90 % of the target volume of heat (72 Mtoe) from renewable energy sources by 2010. This compares to 43 Mtoe in 2002. Biomass also plays a significant role in the target to cover 21 % (or 162 TWh) of the demand for electricity by means of renewable energies by 2010. As part of that target, biomass was originally expected to supply 68 % (or 110 TWh) of the needed growth in the production of renewable electricity between 1997 and 2010, but was reduced to 40 % (or 65 TWh) of this growth. This compares to 27 % in 2002 (or 43 TWh). Thus, bioheating, bioelectricity and biofuels are growing much more slowly than envisaged in the EU directives, and this is the main reason why the overall target for the use of renewable energy sources in the EU-15 is not likely to be met by 2010 (European Commission, 2004c).

Technology trends

Some technologies for biomass and waste combustion are already competitive with oil in locations where wood residues are available nearby and where the combustion of municipal wastes saves the cost of transport to, and depositing in, scarce landfill sites. However, in most heating and electricity applications biomass energies need subsidies or tax reductions to become competitive with oil and gas, and the conversion of biomass into liquids is generally not competitive with oil either (European Commission, 2005c: 37-41).

There are five fundamental forms of bioenergy use (Larsen et al., 2003: 19-20):

1. Traditional domestic use in developing countries, burning firewood, charcoal or agricultural waste for household cooking, lighting and space heating.
2. Traditional industrial use for processing tobacco, tea, pig iron, bricks, tiles etc.
3. Modern industrial use in which industries are experimenting with technologically advanced thermal conversion technologies.
4. Newer chemical conversion technologies (fuel cells). These are capable of bypassing the entropy-dictated Carnot restriction that limits the conversion efficiencies of thermal conversion units.
5. "Biological conversion" techniques, including anaerobic digestion for biogas production and fermentation for alcohol, e.g. from lignocellulosic raw material.

Although many biomass technologies are considered close to maturity, there is still a need for efficiency and cost-effectiveness improvements, cf. the table below.

Table 5. Status of development for selected biomass conversion technologies

Technology	Development stage
Fermentation to bio-ethanol	Commercial status, but high cost, low efficiency and low yield (~55 Gj/ha with cellulose, 75 Gj/ha with hemicellulose). Challenges are: cost reduction, higher yield, use of hemicellulose, and use of lignin.
Physical processes to biodiesel	Proven technology with high cost and low yield (~40 Gj/ha). Challenges are: use of byproducts, cost reduction and continuous production.
Anaerobic digestion	Commercial status but digesters. High cost, low efficiency and low yield. Challenges are: scale-up, cost reduction and use of mixed waste.
Combustion	Commercially available but emission problems and low efficiency at small scale (~170 Gj/ha for heat, ~50 Gj/ha for electricity). Challenges are: emissions, feedstock availability, feedstock contamination and combustion stability.
Gasification	Technology at demonstration scale, with moderate cost and high efficiency, increased in CHP (~80 Gj/ha for electricity, ~160 Gj/ha for CHP). Challenges are: gas quality, cost reduction, economic downscaling for liquid fuels and hydrogen.
Fast pyrolysis	Technology at development stage for fuel, with moderate cost, moderate efficiency, producing biofuels that can be stored and transported, used as fuels or chemical raw material. Challenges are: product quality and standards, application development, integration in bio-refinery.

Source: Supergen Initiative workshop, 2003, cited by Jitex, 2004: 21.

The available biomass resource in most EU countries is rather limited. Growing energy crops could potentially increase the domestic supply of biomass. Energy crops are generally not economically viable, but might become so in the EU in the future if there is a continuing need to take agricultural land out of food production and find other uses for it, if the economic benefits of lower emissions of greenhouse gases are taken into account or if fossil fuel costs increase substantially. A sustainable deployment of biomass thus depends on its complete life cycle. Among other things, SWOG proposes that EU-wide R&D should aim at breeding plants that are optimised for energy use (European Commission, 2005c: 37-41).

Converting biomass into liquid fuels is important if biofuels are to substitute oil in the transport sector. SWOG therefore advocates that EU-wide R&D should aim at finding more efficient and cheaper processes for converting biomass into liquids. Furthermore, liquid biofuels hold the advantage over solid biomass and biogas that large-scale international trade is feasible. Thus, Europe could in principle import liquid biofuels from other areas of the world holding vast biomass resources. However, at current oil price levels, such imports are not economical unless biofuels receive subsidies or tax reductions (European Commission, 2005c: 37-41).

<u>Strengths and weaknesses for Europe</u>

Europe is considered a leader in *scientific and technological* capabilities for biomass and several Member States are world-leaders in their respective fields. The technology networks are considered important for the exchange of information between scientists and developers of gasification and fast pyrolysis, but there is a need to exchange of experiences and best practises across Member States and also with regulators and policy-makers. Research efforts in FP5 covered the whole chain from production of feedstock to end-use as well as socio-economic studies on life cycle assessment of biofuels, opportunities for Eastern Europe and optimisation of biofuels introduction (see for example www.viewls.org). However, it seems to be a challenge how to balance support for very innovative technologies and the need to develop more robust, simple and effective technologies. Research into the use of and increase in bio-energy byproduct is also rather scarce and fragmented at European level. Compared to the USA, European R&D budgets are much lower and priorities are more fragmented.

Regarding *markets and industry*, Europe has become a market leader in electricity generation using biomass in conventional steam cycle power plants. Especially Nordic industry has become the main producers and exporters of equipment and services for bioelectricity generation. This is mainly due to large domestic markets, low-cost biomass resources, strong paper and pulp industry and favourable national policies.

Favourable legislation and policy targets and directives at European level favour biomass energy production. Also at national level, support schemes are implemented such as for example the Danish support scheme for bioelectricity and the German support schemes for bioelectricity and liquid biofuels. However, the EU targets are not compulsory for the Member States, and incentives are not coordinated, and experiences related to the implementation are not shared (Jitex, 2004: 27-30). For example, important volumes of raw materials are exported to Germany because liquid biofuels are strongly subsidised there compared to Italy, France and Spain (Jitex, 2004: 28).

In *conclusion*, new science and technology opportunities could be pursued in biofuels made from the cost-competitive cellulosic raw materials. The FP5 project TIME with a research team from Finland, Denmark, Hungary, Italy, Sweden and the Netherlands looked into lignocellulosic conversion, and in Sweden a pilot plant has been in operation since 2004 producing ethanol from wood.

New opportunities for the European biomass industry lie within the development of new and more efficient technologies and processes for producing liquid biofuels and in designing new plants optimised for energy use, balancing tradeoffs between high yield, fertiliser requirements and environmental impacts. Also, some new Member States may have good agricultural and forest opportunities regarding biomass production though the exact biomass potential needs further evaluation. The potential of biomass energy outside the EU, in Asia, Africa and South/Central America, is great. Those countries, which use wood and agricultural waste as fuels, would benefit greatly from using their biomass resources more cleanly and efficiently. This poses a major opportunity for European companies (European Commission, 2005c: 37-41).

Major threats to the development of bioenergy in Europe are the limited volume of biomass resources available for energy production and the relatively high price of these resources. The potential for dedicated biocrops is limited by competition over available land areas with other potential uses such as food, paper and pulp production and by unfavourable economics at current fossil fuel price levels. Furthermore, there is currently European opposition to genetically modified crops and the lack of integrated policies between the agricultural and energy sectors to achieve the targets at EU and Member States level hinder the development of biomass as an energy supply source (Jitex, 2004: 27-30).

Hydrogen and Fuel Cells

Overview

Hydrogen used as an energy carrier is generally accepted as a promising future replacement of fossil fuels, able to address the issues of environmental degradation and energy supply. The notion of the hydrogen economy has become a hot topic for decision-makers in government and industry all over the world. Visions, proactive actions and investments are paving various pathways to the hydrogen future, from economic world powers such as the USA and Japan to small nation states such as Iceland and Singapore. International collaborative efforts are likewise undertaken, including the International Partnership for the Hydrogen Economy (IPHE), the Hydrogen Coordination Group of the International Energy Agency etc. However, a variety of critical issues remain to be solved. These include developing efficient and clean production technologies, reducing hydrogen production costs, building a hydrogen infrastructure and developing efficient, durable and cost-effective fuel cells. Further safety codes and standards for hydrogen production, storage, distribution and end-use should be developed (Larsen et al., 2004).

The development of a hydrogen economy, with H_2 produced from renewable energy sources, is a long-term objective of the European R&D agenda, and substantial funds have been allocated over the years to pave the way.

Technology trends

Hydrogen technologies comprise a variety of technologies from production over storage and distribution to end-use technologies in different application areas.

Production technologies consist of three main routes: the conversion of hydrocarbon (thermochemical process by partial oxidising, reforming, biomass gasification or pyrolysis), electrolysis of water by electricity (electricity produced by a variety of sources including fossil fuels, nuclear and renewables) and the more longer-term route of direct water-splitting technologies including photolytic production and high-temperature thermochemical cycles. Ninety-eight per cent of current industrial production of hydrogen is generated from hydrocarbons. The challenges and benefits of each technology are very different in terms of cost, impact on security of supply and GHG emissions, as illustrated in the table below.

Table 6. Costs and impacts for different production technologies

	Natural gas (SMR)	Grid electricity (electrolysis large scale 1000kg/d)	Wind (electrolysis)	Biomass (gasification)
Hydrogen cost (excl. distribution)	1.0 €/kg (8.3 €/GJ)	3.75 €/kg (31.3 €/GJ)	6-8 €/kg (50-67 €/GJ)	3-4 €/kg (25-33 €/GJ)
Positive impact on security of supply	Modest	High	High	High
Positive impact on GHG emissions reduction	Neutral – modest	Negative – neutral	High	High

Source: European Hydrogen and Fuel Cell Technology Platform. Draft Deployment Strategy. Version 6 December 2004.

In the short term, further developments of small-scale reforming (efficiency and cost), on-site electrolysis (reliability and efficiency) and biomass gasification are expected in relation to demonstration projects of fuel cell technologies. Biological and high-temperature thermochemical processes have a long-term perspective, and technological breakthroughs are needed.

Storage technologies comprise the following options: compressed hydrogen, liquid hydrogen and storage by adsorption (in metal hydrides, chemical hydrides, storage in nano-tubes). For mobile applications, the technical challenge is how to store sufficient hydrogen required for a conventional driving range. For stationary applications, weight and volume are less restrictive, but low-cost, energy-efficient storage of hydrogen is needed throughout the hydrogen delivery system infrastructure. Hydrogen storage in metal hydrides is considered the most promising in the field of transportation, but products are still too heavy, too costly and suffer from degradation over time. The most common technology in present fuel cell vehicles is compressed gas cylinders. For these technologies, further research is needed on high-pressure storage (up to 700 bar) and materials. Liquid hydrogen has a better energy density compared with compressed gas, but due to the low temperature (- 253º C), efficient insulation and boil-off losses are a major concern.

End-use technologies
Fuel cells are considered the most promising of the end-use technologies due to their higher efficiency and better environmental performance. In terms of the global number of units built, the most dominant fuel cell type is Proton Exchange Membrane Fuel Cell (PEMFC) with more than 70 % of all systems. It is used in portable applications, vehicles and stationary applications.

Small-scale residential applications (1-10 kW) have increased recently with 1,400 new systems built in 2003-2004. PEMFC remains the technology of choice although Solid Oxide fuel Cells (SOFC) are also widely used (1/3 of the total in 2004). Large-scale residential applications (more than 10 kW) comprised more than 700 units installed worldwide by 2004. Up to 2002, the most predominant technology was Phosphoric Acid Fuel Cell (PAFC), but today Molten Carbonate Fuel Cell (MCFC) systems account for 40 %. Most large stationary fuel cell makers are developing SOFC systems, and the share is growing (Jitex, 2004: 33).

The number of fuel cell vehicles worldwide is approximately 300 light-duty vehicles and 65 buses. PEMFC is the technology of choice. Further technical challenges are related to the membrane, the electrode costs and the lifetime and stability of the stack. Mass production and the associated cost reduction (by a factor 20) are closely related to the development of a hydrogen infrastructure and cost-competitive hydrogen. Competing technologies are hybrid vehicles already on the market (Jitex, 2004: 34, 36).

RD&D recommendations focus on cost-effective production technologies, storage technologies, materials and production technologies related to fuel cells and large scale demonstrations in transport, stationary power and portable applications (see for example European Hydrogen and Fuel Cell Technology Platform, 12 March 2005; European Commission, 2005c).

<u>Strengths and weaknesses for Europe</u>
In the area of *science and technology*, Europe has a good fundamental research capacity especially in the fields of chemistry, materials science and energy systems. This is important in various hydrogen and fuel cell technologies. Research funds have increased over the years in the Framework Programmes. Since the 1970s, the EU has supported research, technological development and demonstrations in the area of hydrogen and fuel cell technologies. Funding has grown from 8 million € in the Second Framework Programme (1988-1992) to more than 130 million € in the Fifth Framework Programme (1999-2002) (EU Commission, 2003a: 5). In the Sixth Framework Programme (2003-2006), the budget for sustainable development and renewable energies has increased to 2.1 billion €, of which 250-300 million € is expected to be earmarked for hydrogen and fuel cell R&D. Citation analysis in the field of fuel cells demonstrates that half of the top-20 nations are European, with Germany as No. 3, the UK as No. 4, Italy as No. 6, Denmark as No. 7 and Sweden as No. 10 (http://esi-topics.com/fuelcells/index.htlm). The focus of FP5 and FP6 has been on technologies with the highest attractiveness, including PEMFC and SOFC.

Several European demonstration projects have focused on niche markets, including hydrogen production from renewables and conversion in remote locations, auxiliary back-up power for residential homes, and the CUTE/ECTOS demonstration project of 33 buses in 10 cities with 10 fuelling stations and a total budget of 100 million €.

Several efforts have been made to coordinate activities in hydrogen and fuel cell technologies at European level to overcome fragmented R&D across countries and sectors, including European networks of excellence, networks like SOFCNET, networking of national and regional programmes (FP6 Hy-Co ERAnet), European Technology Platform for Hydrogen and Fuel Cells and the FP6 Hyways project regarding making hydrogen roadmaps for several Member States.

Regarding *markets and industry*, Europe is leading in the field of industrial hydrogen production, conditioning and distribution with key players like Linde and Air Liquide. Several companies are developing processes for biomass gasification, including Ahlstrom and Gotaverken. In conventional electrolysis, Hydro is one of the leading manufacturers (Jitex, 2004: 67). Patent analysis shows that since 1996, a dramatic increase in worldwide patent activities in hydrogen production, distribution, storage and fuel cells has taken place (Wietschel, 2004). The leading countries are Japan (30 % of all patents), the USA (29 %) and Germany (22 %), followed by the UK (4 %) and Canada (4 %). Denmark, France and the Netherlands as well as Australia and Korea also have relevant patent activity. The EU-15 has a leading role in steam reforming based on patents in Germany, the UK and Denmark. The USA is the leading country in partial oxidation patents. Electrolysis and gasification play a minor role.

According to the patent analysis, Japan plays the leading role in fuel cell patents (33 %), closely followed by the USA(30 %) and the EU-15 (30 %), but Germany alone has 18 % (Wietschel, 2004). Europe has a good position in SOFC with a strong commitment among European companies, and in the field of small-scale CHP, the European market seems to offer more possibilities than the American market.

In contrast, European PEMFC manufacturers do not seem well-positioned to get into the automotive market compared with North American companies (Jitex, 2004: 46). DaimlerChrysler has chosen Ballard together with Ford (who owns Volvo and Jaguar). Fiat is likely to join General Motors using Toyota fuel cells, and Renault and Nissan have in-house fuel cell resources. Some European companies have strong strategic alliances with North American companies, including Veillard with Plugpower and Ahlstrom's agreement with Ballard to develop and manufacture stationary applications for PEMFC in Europe. Besides DaimlerChrysler, the commitment of fuel cell manufacturers is low compared with American and Japanese companies. This is supported by patent analysis, which reveals that the biggest increases in fuel cell patent activities take place in the automotive industry in the US and Japan whereas the European patent activities have declined in the period 1999-2003 (Thomson Scientific Ltd., October 2004).

Regarding *policies and measures*, in November 2003 the EU Commission launched the Initiative for Growth including the Quick-start Programme with two hydrogen initiatives. Over the next 10 years, an indicative 2.8 billion € has been earmarked to the large-scale production of hydrogen based on fossil fuels and with CO_2 capture and storage (Hypogen) and the building of a limited number of hydrogen communities with stationary and transport applications around Europe (HyCom) (EU Commission, 2003c). The 1.3 billion € Hypogen programme thereby matches the American 1 billion US$ FutureGen project that over a ten-year period will demonstrate the integrated production of electricity and hydrogen from coal, with capture and storage of the CO_2 generated in the process (ESTO, 2005a). The 1.5 billion € HyCom programme on the other hand builds on the successful CUTE/ECTOS projects in transport applications and widens the scope to include other transport applications as well as stationary and portable applications and thereby profiles European demonstration projects as integrated, comprehensive community projects vis-à-vis American, Canadian and Japanese demonstration activities (ESTO, 2005b).

Important is also the launch of the European Hydrogen and Fuel Cell Technology Platform in January 2004 with more than 200 stakeholders European-wide. The platform is a major European, mission-oriented initiative which aims at strengthening the capacity to organise and deliver innovation in Europe (www.hfpeurope.org). Though led by the industry, it is strongly supported by the EU Commission, which encourages the process and closely coordinates its activities in this area and where appropriate use the work of the platform when developing research policy (European Commission, 2004g; European Research Advisory Board, 2004). A Strategic Research Agenda as well as a Deployment Strategy were recently endorsed by the managing body of the platform, the Advisory Council, in December 2004.

Regarding CO_2 emissions, the current regulations do not give any advantages to fuel cells using hydrogen produced by low-CO_2 processes. The German feed-in tariff for stationary fuel cells of

5.11 €c/kWh does not distinguish between the fuel used in fuel cells. But other European policies and regulations address this topic, including the adoption of the Kyoto Protocol, the policy targets on renewables, the voluntary environmental agreements with industry on lower emission standards etc. (See the section above on EU policy responses).

Regarding international cooperation, the EU Commission and several member States are represented in the International Partnership for Hydrogen Economy (IPHE).

In *conclusion*, European research teams have a great opportunity for addressing some of the major needs of breakthroughs for several hydrogen and fuel cell technologies, involving chemical processes and materials developments. With the Strategic Research Agenda and the Deployment Strategy made by the Technology Platform, there is now also a good foundation for streamlining all European efforts. A market opportunity for hydrogen and fuel cell technologies does not exist in the medium term, except for some niche applications. Stationary applications may appear earlier on the market, and Europe's position in the development SOFC is quite good. European industries do not have a leading position in manufacturing of PEMFC or MCFC, but might have opportunities in the balancing of systems. With the launch of the two hydrogen Quick-start initiatives, a push for demonstrations is now being made at a European level and together with the current CUTE/ECTOS demonstration of fuel cell buses and different hydrogen filling stations, this may constitute a good counterweight to ambitious Japanese, American and Canadian activities in the field. Although the EU project Hyways is making roadmaps for the introduction of hydrogen energy for a limited number of Member States, there is still a long way to go when it comes to making and approving a comprehensive European hydrogen action plan for the introduction of hydrogen economy. However, unlike the situation in the USA, the European policy measures are much more diversified, including both technology-push and market-pull measures.

Photovoltaic Technologies[8]

<u>Overview</u>

The global solar electricity market has grown by an average of more than 30 % in the past 5 years. This growth has been generated by national market stimulation programmes, especially in Japan and the EU. Almost half of all photovoltaic systems are used in off-grid industrial and domestic applications in remote areas, and the other half in the grid-connected systems may become competitive in the medium term in peak power applications. More than 1.8 GW of PV capacity was installed in IEA countries by the end of 2003, with 85 % of this capacity installed in Japan, Germany and the USA.

In the table below, an overview is given of R&D expenditure, demonstrations and market stimulation in IEA countries.

Table 7. Public budgets (in US$ million) in PV R&D, demonstration and market stimulation 2003

Country	R&D	Demonstration	Market stimulation	Total
Austria	1.7	-	8.6	10.3
Czech Rep.	11.3	1.1	2.3	14.6
Denmark	3.8	0.8	-	4.6
Germany	33.6	-	757.1	790.6
Finland	0.5	-	0.0	0.5
France	5.8	-	22.6	28.4
UK	4.9	9.4	-	14.3
Italy	5.4	0.2	22.6	28.2
Netherlands	2.4	0.2	54.7	87.3
Sweden	2.1	-	-	2.1
USA	65.7	-	273.7	339.4

[8] This section draws primarily on the Jitex study (Jitex, 2004).

Source: Jitex, 2004 (based on IEA study, September 2004).

Technology trends

The Si-crystalline cells are a mature technology and will dominate the PV applications for the next decades. Thin-film silicon cells could be a solution in case of silicon scarcity and could be used in grid-connected applications. Compound semiconductor cells are very expensive, but could find niche applications as PV concentrating systems. Dye-sensitised cells show instability but could find niche applications such as PV windows, solar home systems etc. Polymer solar cells are still inefficient and unstable, but could be used in buildings.

Technological breakthroughs are needed to accelerate the development of PV, and fundamental research is needed, particularly in materials science, photo-electronics, quantum physics and optoelectronics. European research into organic solar cells is very competitive.

The SWOG report proposes the following R&D priorities (European Commission, 2005c: 35):

- Exploration of novel PV materials, including organics and new production technologies
- Novel thin-film modules and production techniques
- Work on truly mass-producible PV modules, linking device physics with manufacturing technology and material research into promising PV technologies.

Strengths and weaknesses for Europe

In the field of *science and technology*, Europe has achieved a good position within PV research in the past five years. It has a critical mass for science and technology capacity, in particular in Germany. However, 90 % of European public R&D expenditures come from national R&D programmes and there is no formal coordination between these programmes. This makes the research area fragmented and puts Europe at a disadvantage compared to large nations such as the USA and Japan (European Commission, 2005f: 17). Fragmentation is also a problem for European industry. The rapid transfer of technology from research to market is a challenge, and manufacturing issues are generally poorly addressed in technology development programmes. However, FP6-supported coordinating actions are taken to overcome fragmentation, for example the PV Catapult Coordination Action with more than 70 partners from the European industry, the research community and other major stakeholders of the PV sector (see www.pvcatapult.org)

In the EU *market and industry*, the production of PV panels was up 43 % in 2003 with 193 MW produced, and Germany reached 400 MW of installed panels. Italy, France and UK launched PV programmes in 2004 with support to private investors. The EU PV industry has a dedicated export strategy and the European Photovoltaic Industry Association roadmap sets targets of 1 GWp and 30 GWp of cumulated PV systems in third-world rural applications in 2010 and 2020 respectively. However, companies are not competitive with Japanese ones due to limited PV production capacities. The three largest polycrystalline silicon wafer manufacturers are located in Europe and there are also a lot of competitive module, cell and balance-of-system manufacturers. But the market of PV cells is still too closely linked with national programmes of grid-connected PV systems, which is still marginal.

In terms of *policies and other measures*, European standards and codes for PV systems and components are being prepared in accordance with EU directives and international activities. This is important for the future competitiveness of the European PV industry. However, there are larger differences in the regulatory framework of the Member States. Spain, Germany and Belgium have implemented incentive feed-in tariffs, while other Member States have limited market stimulation programmes. In the new Member States, the three Baltic countries have feed-in tariffs, and similar measures are discussed in some of the other countries (European Commission 2005f: 16). A Photovoltaic Technology Platform was established in May 2005 to define, support and accompany the implementation of a coherent and comprehensive strategic plan for PV. The platform will mobilise all stakeholders sharing a long-term European vision for PV, helping to ensure that Europe maintains and improves its industrial position. So far, a vision for PV technologies has been made by the PV Research Advisory Council (PC-TRAC) (European Commission, 2005f).

In *conclusion*, scientific opportunities in PV are closely related to a good starting point and can further be exploited by cutting-edge research in nanotechnologies. Market opportunities are associated with rapid growth in Europe, and this can be further consolidated by a greater presence in export markets, especially in the developing countries. However, it is likely that in a few years' time, low-income countries like India, China and Indonesia might be offering cheap PV systems to these markets (Jitex, 2004: 16).

Clean Fossil Fuels[9]

Overview

The majority of energy today is produced from fossil fuels. Coal is the most abundant fossil fuel and the least expensive, but it is also associated with environmental problems. Petroleum and gas are cleaner fuels than coal and easier to transport and use. Fossil fuels can be used in a variety of technologies that produce electricity, heat or a combination.

An important challenge today is to find better ways of making use of this relatively abundant, cheap and widely used fossil fuel while at the same time minimising the environmental impacts. Three approaches to meeting such challenges of making the use of coal more attractive and less polluting are (European Commission, 2005c: 44):

- Efficiency improvement of current methods by modernising or replacing plants
- Cleaner technologies
- CO_2 capture and storage

Also international collaboration is conducted in the field of CO_2 capture and storage. In June 2003 on the initiative of the USA, the Carbon Sequestration Leadership Forum (CSLF) was founded by 16 countries and the European Commission (www.cslforum.org). It is an international climate change initiative that is focused on developing improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage. The purpose of the CSLF is to make these technologies broadly available internationally and to identify and address wider issues relating to carbon capture and storage.

Technology trends

Efficiency improvement. The world average efficiency of electricity generation from fossil fuels is about 30 %, the EU average is about 35 % and is expected to be 50 % in 2010 in advanced coal-fired plants. It is therefore crucial to improve plant efficiency, both by modernising older ones and by constructing more efficient new ones.

Gas turbines cover a wide range of applications and sizes. Significant progress has been made on gas turbine technology, and it is now considered a mature technology. However, although Natural gas-fired combustion cycles (NGCC) are widespread, technical barriers remain in relation to efficiency and operating temperatures, which will require new concepts and cycles to be developed.

Coal-fired power generation technologies are also well established and widely used, including pulverised fuel combustion (PF) with sub-critical steam driving a steam turbine, cyclone-fired wet-bottom boilers and stoker boilers for small-scale applications.

SWOG recommends support and coordination of R&D on (EU Commission, 2005c: 45):

- High-temperature materials and generic components design, which ultimately will enable the various combustion engines to achieve higher efficiencies.
- Development and demonstration of Steam Turbines with Supercritical Steam (STSS)

[9] This sections draws primarily on the Jitex study (Jitex, 2004).

- Systematic collection of experience with the cogeneration of more than one fuel, including coal mixed with biomass, waste or oil and gas.

New cleaner technologies being developed are, for example, pulverised fuel combustion with supercritical steam driving a steam turbine, atmospheric pressure fluidised bed combustion (FBC), pressurised fluidised bed combustion (PFBC) and intensified gasification combined cycle (IGCC). The most commonly used advanced coal-based technology is pulverised fuel combustion with supercritical steam cycle plants, but further development is needed to operate at higher temperatures and at very high pressures. In the early 1990s, the IGCC technology started, and demonstration plants of 250-300 MW are now in operation, two in Europe and two in the USA. The next generation of IGCC plants is now under way worldwide, focusing on non-capture IGCC, improvement of refinery IGCC and demonstration of capture of coal IGCC. These are the FutureGen in the US, EAGLE (demonstration plant) in Japan, CO2CRC in Australia and two demonstrations led by the Canadian Clean Power Coalition. The EU Hypogen project has not yet decided which technology to use for the large-scale production of hydrogen based on fossil fuels and with CO_2 capture and storage (either natural gas steam reforming or coal gasification) (ESTO, 2005a).

SWOG recommends further R&D in (European Commission, 2005c: 46):

- High-temperature materials in PFBC and development units of PFBC with new materials, components design and manufacturing techniques.
- Development of coal gasification technology, including hot-gas-clean-up techniques
- Development of CO_2-capture-ready combustion technology, including combustion systems that make CO_2 capture easier, and chemical looping.

In addition to improving the efficiency and emission levels of the conversion technologies, efforts are made to develop near zero-emission technologies, which combine advanced power production systems with *CO_2 capture and storage*. Three main technologies are (Jitex, 2004: 75)

- Post-combustion capture, where CO_2 is extracted from the flue gas, well adapted for retrofilling
- Pre-combustion capture, which leads to a high CO_2 concentration steam and separation of CO_2.
- Oxy-fuel technologies, where the combustion in oxygen leads to high CO_2 concentration in the flue gas.

These CO_2 capture technologies involve adsorption, absorption (chemical or physical), membrane separation or cryogenics. They all result in efficiency loses and therefore increase costs.

CO_2 storage in geological formations includes depleted oil and gas reservoirs, unmineable coal seams, aquifers etc. Further, CO_2 can be injected into almost-depleted oil fields to enhance oil production. The Enhanced Oil Recovery process (EOR) is commonly used, especially in the USA. Enhanced Gas Recovery (EGR) is not presently used, and there are only a few Enhanced Coal Bed Methane (ECBM) trials worldwide.

SWOG recommends R&D in (EU Commission, 2005c: 30):

- Improved or new processes, which can separate and capture CO_2 more cheaply in exhaust gases. R&D to explore new ideas should be given high priority.
- Proving long-term CO_2 capture, aiming at demonstrating the safety and viability of different CO_2 storage options and eliminating long-term risk.

<u>Strengths and weaknesses for Europe</u>

Science and technology. Except for development projects on hydrogen production and CO_2 capture and storage, clean fossil energy technologies have been left out of the EU FP6. As fossil fuels still remain the major energy source for the next few decades, it is seen as a major weakness that these short/medium-term technologies are not properly addressed in the EU's R&D

priorities, also to catch up with the USA and Japan in this domain (Jitex, 2004; EU Commission, 2005c). The development of gas turbines was supported in FP4 and FP5, but this development has not been followed by demonstrations as, for example, in the USA. FP6 does not address the improvement of power production efficiency in gas turbines.

In the area of CO_2 capture and storage, the EU supports projects such as the Weyburn CO_2 Monitoring Project in Canada, one project demonstrating CO_2 storage in deep aquifers in the North Sea (Sleipner) and an assessment of the European potential for geological storage of CO_2 produced by the combustion of fossil fuel (GESTCO). Especially the Sleipner project initiated by Statoil has become a world-class project with many European partners and international companies that have the opportunity to gain hands-on experience in process, safety and reliability. In FP5, the total expenditure on CO_2 capture and storage R&D was 32 million €, with an EU contribution of 16 million €. In FP6, 37 million € of EU funding, matched by an equivalent amount of public and private investment has been allocated to research, development and demonstration, and new calls are foreseen (European Commission, 2004i). Three larger projects (Integrated projects) focus on enhanced capture of CO_2 (ENCAP), CO_2 from capture to storage (CASTOR) and in-situ laboratory for capture and storage of CO_2 (CO2SINK).

With the announcement of the Hypogen initiative in November 2003, the EU Commission has given priority to a large-scale test facility for the production of hydrogen and electricity from fossil fuels and with CO_2 capture and storage. The indicative funding of 1.3 billion € is expected to come from EU, national, regional and private sources, but although it is very much equivalent to the US FutureGen in terms of funding and objective, no decision has yet been made concerning technology, organisational set-up or funding (Esto, 2005a).

The German COORETEC has announced the study of a third-generation capture IGCC, including CO_2 capture combined cycle, hydrogen turbine specification and improvement of gasification. The study will be made by Siemens, Lurgi, RWE, Vattenfall, Eon, IEC and Linde.

The five-year Norwegian programme of KLIMATEK with its 70 million US$ budget promotes technologies aimed at reducing greenhouse gas emissions. Projects supported are, for example, the international Carbon Capture Project (CCP) undertaken by seven global energy companies as well as long-term national research projects (www.co2captureandstorage.info).

The R&D activities in Europe are considered fragmented. Some efforts have been made to coordinate R&D activities on cleaner fossil technologies at European level to overcome this fragmentation across countries and sectors:

- Centres of Excellence for Industrial Gas Turbines (CE-IGT supported by FP5)
- POWERCLEAN is a FP5-funded thematic network focusing on coal and other fuel-based technologies.
- CO2NET is a network of researchers, developers and users of CO_2-technology (supported by FP5)
- CO2GEONET is a network of excellence on geological storage supported by FP6.
- 2003 FENCO (The Cleaner Fossil Energy Coalition) is a Specific Supporting Action (SSA) within FP6 that aims at creating a European research area network (ERA-net) in fossil energy. Some Member States already have programmes addressing the transitional use of clean fossil fuels, including the German COORETEC (CO_2 reduction Technology) and the British Carbon Management Strategy for Fossil Fuel. The overall aim is to coordinate the national level of funding in this area.

Market and industry. The power plant market is currently in a wait-and-see situation due to uncertainties related to CO_2 taxes and other regulations as well as public concern. Nonetheless, old plants need to be replaced, and new capacity may be needed as well. On the international markets, China and India are expected to be the largest markets for clean fossil energy in the near future.

Over the past decade, US gas turbine technologies have attained a dominant position on the market. Within advanced PF systems, the EU industry and the Japanese industry are world-leaders. Europe also has advanced CFB and PCFC plants as well as the Puertollano gasification plant running since 1998. The micro-turbine market in Europe is in its early stages with approx. 300 demonstration units installed, most of which are natural gas-fired and used for cogeneration.

There is no CO_2-EOR production in Europe today. However, the project CENS (CO_2 for EOR in the North Sea) plans to start operating the CO_2 capture facilities in Denmark and the UK in 2007, and there is also an EU-supported large-scale demonstration project for ECBM in a Polish coalfield.

However, all in all, Europe is lagging behind compared to the USA and Japan, which are world-leaders in commercially available absorption technologies, a market position that is also supported by R&D into membrane technologies (Jitex, 2004: 112).

In terms of *policies and measures*, there are many uncertainties in Europe, especially regarding CO_2 allowances and taxation. However, compared to the USA, policies and measures for distributed generation are favourable, and European legislation also plays an increasingly important role in defining the framework conditions for cogeneration, including the directive on the promotion of cogeneration. Also, the directive establishing a scheme for GHG emission trading allows European stakeholders to gain some benefits, including the development of cost-effective storage technologies in the North Sea and the establishment of a market for CO_2 capture and storage technologies.

On the initiative of the European Commission, an important step was taken in March 2005 to call for the creation of a Technology Platform for Zero Emission Fossil Fuel Power Plant. The initial scope of the Platform aims at identifying and removing the obstacles to the creation of highly efficient power plants with near-zero emissions which will drastically reduce the environmental impact of fossil fuel use, particularly coal. This will include CO_2 capture and storage, as well as clean conversion technologies leading to substantial improvements in plant efficiency, reliability and costs. It is, however, too early to judge the coherence, strength and effectiveness of the platform, which is planned for founding later in 2005. Regarding international cooperation, the EU Commission and several Member States are represented in the Carbon Sequestration Leadership Forum (CSLF) and the International Partnership for Hydrogen Economy (IPHE).

In *conclusion*, scientific opportunities relate to efficiency improvement of well-known technologies as well as cleaner technologies and CO_2 capture and storage. This includes a stronger effort within advanced PF, CBF power plants and the development of commercial IGCC and PFBC power plants. The future market development will primarily be in China and India, but Europe seems to lag behind both Japan and the USA in these markets. The markets for CO_2 storage are very promising, but again Europe is lagging behind due to the fact that the USA and Japan are leaders in commercially available absorption technologies, a position which is further sustained by strong American R&D effort (Jitex, 2004: 102). As there is a significant CO_2-EOR potential in the North Sea, excellent opportunities exist for implementing a major infrastructure for CO_2 gathering and transportation. But again major threats to such a project are related to the absence of a legal framework similar to the USA's "underground waste injection" or Norway's natural gas regulations, something which could last for years.

Nuclear Fission

<u>Overview</u>

The discovery of nuclear fission was a European effort. Following the development of the nuclear bombs and their use in World War II, efforts were focused on the peaceful use of nuclear power. The first electricity-generating plant was made in Idaho in 1951, and large-scale power production began in Calder Hall in the UK in 1956. Major nuclear power investments were first made in the 1960s and 1970s in the USA, Japan, Russia, France, Germany, Spain, Finland etc. Today, there are some 440 nuclear power plants worldwide in 31 countries, and about 30 are under construction. More than 90 % of these plants are light-water reactors (LWR). Nuclear power provides 17 % of the electricity generated worldwide, 31 % in the EU-25 and 78 % in France (European Commission, 2005c; Lauritzen et al., 2005).

Fission R&D has, together with fusion, been part of the Community research programme since the inception of the Euratom Treaty in 1957. From the beginning, fission R&D covered the whole fission-related cycle, including fuel enrichment and fabrication, various types of reactors, reprocessing and waste treatment, storage and final disposal. Safeguards and radiation protection were also included.

Some of the advantages of nuclear fission are widespread and abundant uranium ores, it is a concentrated energy source and does not produce GHG. Further, costs are mainly related to the technology, and some fission reactors can also generate high-temperature heat, which could be used for other processes and for hydrogen production. However, after some serious accidents at the Three Mile Island in Pennsylvania in 1979 and at the Chernobyl plant in Ukraine in 1986, public and political concern has emerged regarding safety. Also, serious concern is raised concerning the disposal of radioactive waste. However, as nuclear power does not produce GHG, the challenges to cope with global warming and increasing fossil fuel prices may give nuclear power a revival in some countries.

According to a recent study, for a large expansion of nuclear power to succeed, four critical problems should be addressed (MIT, 2003):

- Cost. Nuclear power is not competitive with coal and natural gas at current prices in liberalised markets, but especially carbon emission credits may give nuclear power a cost advantage in the USA.
- Safety. There is a need for best practices in the construction and operation of modern safer reactor designs.
- Waste. Geological disposal is technically feasible, but the long-term waste management benefits of advanced, closed fuel cycles are outweighed by short-term risks and costs.
- Proliferation. Risks of proliferation from operation of the commercial nuclear fuel cycle should be minimised. There are concerns regarding existing stocks of plutonium, nuclear research facilities with inadequate control and transfer of enrichment and reprocessing technology. The current international safeguards institution is inadequate to address these risks.

Regarding the technological challenges, efforts are made in two international fora to conduct R&D into new, cheaper and safer reactor types and find viable solutions to the waste problem. These are:

- In 2001, the US Department of Energy (DOE) initiated the Generation IV project and later transformed it into the Generation IV International Forum (GIF) with ten countries to coordinate R&D on a generation IV reactor type (See appendix for further details).
- Also in 2001, on the initiative of Russia, the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established under the auspices of the International Atomic Energy Agency (IAEA) and with 20 IAEA Member States and the EU (See appendix for further details).

The two international fora have the same objectives, terms of reference and timescale for the next generations of reactor types. There is also a major overlap in membership except for the USA only being a member of GIF and Russia only being a member of INPRO due to disagreements concerning the appropriateness of Russian exports of a nuclear reactor to Iran (Lauritzen et al., 2005: 20).

Regarding proliferation, this is regulated by the International Atomic Energy Agency (IAEA), which is the world's centre for cooperation in the nuclear field. In 1968, the Treaty on the Non-

Proliferation of Nuclear Weapons (NPT) was approved. It essentially freezes the number of declared nuclear weapon states at five (USA, Russia, the UK, France and China), but with nuclear weapons programmes in countries like Pakistan, India and the Democratic Republic of Korea and more or less successful attempts in countries like Iraq and Libya, serious doubts have been expressed regarding the IAEA safeguards.

Technology trends

The research priorities proposed by SWOG aim at addressing safety and security in nuclear power plants as well as the safe final disposal of radioactive waste. Only thereby, will it be possible to overcome the public and political concern about nuclear power. More specifically the R&D actions comprise (European Commission, 2005c):

- Development of innovative power plant through the Generation IV International Forum (GIF). "Generation IV" nuclear energy systems are an ensemble of nuclear reactor technologies that could be deployed by 2030 and present significant improvements in economics, safety and reliability and sustainability over currently operating reactor technologies. The following technologies are addressed in GIF's technology roadmap: Gas-cooled Fast Reactor (GFR), Very-High-Temperature Reactor (VHTR), Supercritical Water-cooled Reactor (SCWR), Sodium-cooled Fast Reactor (SFR), Lead-cooled Fast Reactor (LFR) and Molten Salt Reactor (MSR). SWOG does not argue why the EU's R&D should be done in the GIF framework and not in the framework of INPRO or whether there could be some synergies.

- Validation of models and technology for geological waste disposal.

- Development of better spent-fuel treatment, including partitioning and recycling processes. Further, the impact of advanced spent-fuel treatment on waste repository design and performance should be addresses.

- Better understanding of the effect on human health of low-dose radiation.

Strengths and weaknesses for Europe

Science and technology. Resources allocated to fission have remained stable over the past 17 years. The nominal nuclear EU expenditure through the Joint Research Centre has been approx. 300 million € in each FP, and this also holds for the indirect support to research on fission topics with an average value of 190 million € (World Energy Council, 2001: 99).

European R&D into safer and more efficient nuclear power plants is carried out at various institutions, including:

- CERN (European Organization for Nuclear Research) is the world's largest particle-physics centre. Founded in 1954, the laboratory was one of Europe's first joint ventures and now includes 20 Member States.
- OECD Halden Reactor Project. The Halden Reactor Project has been in operation for more than 40 years and is the largest Nuclear Energy Agency project. It brings together international technical networks in the areas of nuclear fuel reliability, integrity of reactor internals, plant control/monitoring and human factors. The programme is primarily based on experiments, product development and analyses carried out at the Halden establishment in Norway, and is supported by approximately 100 organisations in 20 countries.
- Joint Research Centre Petten. The JRC is the European Union's scientific and technical research laboratory and an integral part of the European Commission. The centre's nuclear research focuses on both nuclear safeguards and nuclear safety.
- Commissariat a l'Energie Atomique (CEA). The CEA is a French public institution involved in fundamental and technological research related to nuclear technology.
- Forschungszentrum Karlsruhe with a R&D programme on nuclear safety and safety of waste.

- SINTER, the University of Stuttgart, Institut für Kernenergie und Energiesysteme.

Three European networks on structural integrity aspects of ageing nuclear components are:

- AMES (Ageing Materials Evaluation and Studies). The network brings together the 'centres of excellence' for materials assessment and research on Reactor Pressure Vessels (RPVs).
- NESC (Network for Evaluating Structural Components). The NESC network conducts large-scale experimental projects to validate the structural integrity assessment process for ageing nuclear power plant components. The results are intended to integrate fragmented R&D and promote best practices at a European level (http://safelife.jrc.nl/nesc/)
- ENIQ (European Network for Inspection Qualification). The overall objective of ENIQ is to coordinate and to manage at a European level expertise and resources for the qualification of non-destructive evaluation inspection techniques and procedures primarily for the in-service inspection of nuclear components (http://safelife.jrc.nl/eniq/).

After the major accidents in the USA and Ukraine, the building of new nuclear power plants came almost to a complete halt. Sixty per cent of the OECD nuclear capacity was built before 1973, 20 % in 1974-79 and 20 % more recently. The average plant age is 21 years, and a total of 107 reactors with an average of also 21 years have been closed down permanently. The problem is, however, that it costs almost the same to close down a reactor as it does to build a new one (Schneider & Froggatt, 2004).

The 3 billion € new plant under construction in Finland is a European Pressurised Reactor (EPR) and has been commissioned to French Areva and German Siemens. It has a design lifetime of 60 years and will produce 1600 MWe. Avera is also involved in the construction of a new EPR demonstration plant in France with a size of 1800 MWe and at a cost of 2.8 billion €. These new constructions will give Avera valuable technical competences in the next generation of plants (Lauritzen et al., 2005: 8).

New plants are also under construction elsewhere, with China, India, Japan and the Republic of Korea as the most active countries. The future *markets* for fission technologies are very much associated with the markets in the fast-developing economies in China, India and Brazil. In December 2004, the American state secretary of energy stated that China would be number one in the world in nuclear power. In 2020, China expects to double its nuclear power from 2 % to 4 % of total electricity production. This will require total investments of 40 billion US$ or some 25 nuclear power plants. The suppliers of these plants will be the front-runners in nuclear technology. Today three companies compete on this market: The US Westinghouse, the French Areva and the Russian AtomStroyExport (Oerstroem Moeller, 2005: 45; Lauritzen et al., 2005).

Policy and measures. Nuclear power exists in 12 EU Member States (France, Lithuania, Belgium, Slovakia, Sweden, Hungary, Finland, Germany, Spain, the UK, Czech Republic and the Netherlands). Further, it is also in countries such as Switzerland, Bulgaria, Romania, all members of Euratom. Public perception has in some countries prevented the introduction of nuclear power (Denmark), and some countries have passed legislation to phase out their nuclear power plants (for example Sweden, Belgium, Germany, the Netherlands, Spain), while some have a moratorium (Switzerland). France, Finland, the Czech Republic and Slovakia have all expressed a positive attitude to nuclear power and new plants are under construction in Finland, Slovakia and the Czech Republic. But all in all, there are serious pressures on how to cope with public and political concern.

Nuclear safety has usually been a national affair in Europe, but recently the European Commission has proposed a directive[10] concerning the safety of nuclear power plants and the processing

[10] Amended proposal for a Council Directive (Euratom) on the safe management of spent nuclear fuel and radioactive waste (COM(2004) 526 final).

of radioactive waste in order to cope with the shortcomings in nuclear legislation in the enlarged EU (Loyola de Palacio, Vice-President in charge of energy and transport, 30 January 2003).

In *conclusion*, fission R&D is founded on strong basic research, and funds have in real terms been relatively stable over the years. Taking into consideration the EPR constructions in Finland and France, this may give European industry a competitive advantage in new emerging markets in China and elsewhere. However, Member States have divergent views on nuclear power and public concern on nuclear safety and waste is outspoken. Recently, EU legislation has been proposed on nuclear safety and waste management to address these issues in the enlarged EU. Regarding international R&D cooperation, European stakeholders seem to be stuck in the middle between two competing fora, and unless Europe makes up her mind to work for a merger or to definitely choose one of the two, this will undermine a coherent and strong EU impact on international cooperation in the field.

Nuclear Fusion

Overview

Fusion is one of the alternatives for the future supply of energy. Fusion is the process which powers the sun and is called fusion because the energy is produced by fusing together light atoms such as hydrogen. However, effective energy production requires a fuel combination, which must be heated to very high temperatures (150 million degrees C) and isolated from contact with the reactor walls by magnetic confinement. Fusion represents some advantages, including abundant basic fuel, inherent safety features, no GHG emissions, and no long-term waste. However, each reactor has to be very large (around 1GW) to allow the required high plasma temperatures to be maintained. The large module size makes development slow and extremely expensive. As a consequence, major research is most properly carried out on a European-wide basis and in cooperation with other international partners.

Fusion R&D has been part of the Community research programme since the inception of the Euratom Treaty in 1957, and it has been part of all Framework Programmes. Since the 1950s, EU Member States and worldwide efforts have focused on creating, controlling and sustaining a fusion reaction by confining and heating plasmas using magnetic fields. In contrast, France, the UK and the USA have programmes on use of lasers (central to nuclear weapons). One single and integrated European programme has ensured that research activities have a critical mass and joint projects such as, for example, the Joint European Torus (JET) have been undertaken. Close to 2000 scientists are working on fusion R&D in more than 20 laboratories, including JET. Collaboration is based on contracts of association with Member States and others associated with the Euratom Framework Programme. Further, the European Fusion Development Agreement lays out the rules for exploitation of the JET facility, international collaboration in support of the so-called ITER (International Thermonuclear Experimental Reactor) and R&D.

Technology trends

Fusion is a long-term technology, and the time frame for large-scale, commercially viable fusion energy is 30-50 years. The JET facility came into operation in 1983 and is regarded as the world’s largest and highest performance fusion experiment. Based on the experiments at the JET and other facilities, a next-step experiment has been under preparation since 1992. The ITER (International Thermonuclear Experimental Reactor) is intended to demonstrate the ability to control and maintain burning plasma for an extended time and also provide experience in the integrated operation of the components. Partners include the EU Euratom partners, Japan, the USA, Russia, China and the Republic of Korea). The estimated cost for the construction of the ITER is around 4.6 billion €. Its construction will take about 10 years, and it is envisaged that it will be in operation for another 20 years. If the experimental reactor turns out successfully, a full-scale demonstration plant is to be built.

SWOG believes that in parallel with the construction and operation of the ITER, preferably in Europe[11], EU R&D should also focus on major technical uncertainties and test fusion reactor materials and components before use in the reactor (European Commission, 2005c). Likewise, SWOG also recommends maintaining some expertise in core plasma physics.

Strengths and weaknesses for Europe

Science and technology. The EU fusion programme represents a well-established, long-term European Research Area, which has pooled expertise and resources around common R&D challenges. This has enabled the EU to play a leading role in the global ITER project (European Commission, 2005e). Considerable resources have been invested over time in fusion research. In FP6, 750 million € are earmarked for fusion R&D, including 200 million € for the possible construction of the ITER.

Though the time horizon of fusion energy is indeed long-term (and tends to be long-term even after 50 years of R&D), there are also important spin-offs of fusion in other areas, which should be taken into consideration when judging the resources invested. Examples of fusion spin-offs are found in medico/health, pulsed power and power conversion, materials processing, superconductivity, space propulsion and waste processing (see details in European Commission, 2003d).

Regarding *policy and measures*, the organisation of a common EU R&D fusion programme has proven successful within fusion energy, a very long-term and resource-intensive field of research. The Euratom Treaty dates back to the birth of the European Community and has benefited from a political wish to use atoms for peace following World War II, including both fusion and fission. The fusion programme is an example of a European Research Area that, by means of a joint vision and pooled expertise and resources, has positioned the EU in relation to other international partners.

In *conclusion*, fusion R&D is a well-established area and with very good reputation internationally. The resource-demanding research area is managed as a true ERA, pooling competencies and resources at EU level. The need to demonstrate value for money in very long-term R&D is related to important spin-offs of fusion R&D. Still, it may be a challenge to attract sufficient funding to very long-term R&D areas in competition with short and medium-term technologies.

Conclusion

Although a European Research Area has not yet been established within key energy technologies, important political steps have been taken, and activities are now under way to realise this ambitious goal. These include the establishment of technology platforms and the opening of national R&D programmes to other Member States. However, the impact of these efforts is yet to be seen, and implementation problems may arise. It is important to remember that European cooperation within energy R&D has a long track record from the founding of the Euratom Treaty in 1957 and the activities in fission and fusion research.

Technology Platforms to overcome fragmentation. In various energy technology fields, technology platforms have been established or are being established in hydrogen and fuel cells, zero emission fossil fuel power plant, photovoltaics and future electricity grid[12]. Although they are established on the initiative of the EU Commission, they are managed by industry and involve academia and national governmental scientific officers. The Hydrogen and Fuel Cell Technology Platform held its second general assembly which was attended by more than 500 participants from industry, academia and governments who came together to discuss well-prepared documents on a Strategic Research Agenda and a Deployment Strategy for hydrogen and fuel cell technologies. The Technology Platform for Zero Emission Fossil Fuel Power Plant and the Technology Platform for Photovoltaics are being established. Priority tasks of the platforms fo-

[11] In June 2005, it was decided that the ITER will be built in Cadarache in France.

[12] See http://www.ired-cluster.org/

cus on setting strategic research agendas and deployment strategies, but also address issues of standards, codes and regulation. It would also, however, be important to address the assessment of the impact of the RD&D efforts undertaken in order to clarify scientific and societal value for money.

Well-established and well-functioning European Research Area in fusion. Apart from these platforms, well-established European collaboration has taken place within fusion energy over the past 40 years. This integrated European R&D programme has assured critical mass and high quality so that Europe today is able to take a lead in the international experimental facility.

Opening up national R&D programmes for other Member States. This is a task yet undertaken by the Mirror Group of the Hydrogen and Fuel Cells Technology Platform in the context of the Hy-Co ERAnet, but also includes experiences of Nordic Energy Research, which since 1992 has pooled R&D funds to common Nordic energy R&D projects.

Each *key energy technology* faces different challenges regarding its scientific base, market developments and policy measures. However, it seems that although fragmentation may be dominant still in most areas, networks and centres of excellence are being established. In most areas, there is a diversified approach to bringing the technologies to the market by combining technology-push R&D with market-pull incentives. The European science base is generally strong in basic research, which is crucial to further developing most energy technologies. However, major challenges seem to lie ahead regarding the technology transfer from science to industry, and in several fields the manufacturing process is poorly developed.

Future opportunities are closely related to making full use of the diversified set-up of technology-push and market-pull measures across the various key energy technologies. In particular, Europe has good opportunities for combining energy efficiency with new, clean, sustainable energy technologies such as biomass and biofuels, hydrogen and fuel cells, PV and other technologies such as wind, ocean, solar thermal and geothermal technologies. More could also be done to ensure that EU initiatives are mutually supportive, for example between agricultural policy and bio-energy R&D. Although there is still a way to go to make a full ERA in key energy technologies, Europe has taken important steps to make use of it for the benefit of own energy systems and markets and also to position European industry internationally. Possible synergies between Member State initiatives should be sought, for example by using networks and technology platforms, which can build upon national experience and include different stakeholders to eliminate fragmentation and duplication of R&D. Europe can use its high-level scientific reputation in various fields to improve and strengthen R&D and industrial relations in fields with emerging markets for new energy technologies, such as bio-electricity generation, FC in stationary and niche applications, PV in developing countries, nuclear power in fast-developing countries, and CO_2 capture and storage in North America.

The major *threats* are associated with implementation problems in the creation of the ERA, public concerns regarding controversial technologies such as GMOs and nuclear power and strong competition from countries like the USA and Japan but also from fast-developing countries like China, India etc.

Table 8. SWOT of European science and technology base in key energy technologies.

	Strengths	Weaknesses
General issues	• Political ambition to create the European Research Area • Political awareness of opening national R&D programmes for other Member States • Technology Platforms established or under establishment in 3-4 R&D major areas • ERA in fusion	• Most energy R&D remains at Member State level, and energy R&D is not coordinated. • The resources allocated to energy R&D are insufficient to prepare Europe for the long-term challenges.
Efficiency	• Political awareness towards energy efficiency • Many market-pull initiatives at EU level, including non-technology support programmes, legislation and information campaigns	• Energy efficiency R&D is not a coherent, profiled research area at EU level. • Relatively few energy R&D funds are allocated to energy efficiency.
Biomass and biofuels	• Strong scientific and technology base in biomass and biofuels and good networks • Leading in electricity generation using biomass in steam cycle power plants • European/Nordic industry is leading producers and exporters of equipment and services for bioelectricity generation • EU legislation in favour of biomass energy production • National support schemes in various countries	• Too much focus on innovative technologies and less on developing more robust, simple and effective technologies • No strong networks/linkages between academia and regulators. • European concern regarding genetically modified crops • Land availability • Lack of integrated policies between agriculture and energy at EU and Member State level • No coordination between different national support schemes and little exchange of experience

	Strengths	Weaknesses
Hydrogen and fuel cells	• Good fundamental research capacity in chemistry, materials science and energy systems • Long-term R&D effort on fuel cells and hydrogen at EU level and good networks in fuel cells • Ongoing highly profiled demonstration in transport (CUTE/ECTOS) • Launch of 2.8 billion € demonstration programmes on hydrogen communities and a large-scale hydrogen production facility based on fossils and with CO_2 capture and storage • European industry leading in steam reforming • Strong position in SOFC for stationary use • Technology Platform well-established and with strategic research agenda and deployment strategy as well as Member State commitment to creating an ERA • Hyways and roadmaps under way in 6 Member States • German feed-in-tariff for stationary FC • Diversified market-pull and technology-push policy measures • EU Commission and several Member States represented in IPHE	• PEMFC manufacturers are not competitive in the automotive market compared with North American companies. • Relatively low commitment to fuel cell cars by European car industry except for Daimler-Chrysler compared with the USA and Japan • No European roadmap for hydrogen economy, including key transition technologies, competing technologies etc.
Photovoltaics	• Good scientific base in PV • Increasing European market for PV and dedicated export strategy • Three European wafer manufacturers and competitive module, cell and BOP manufacturers • EU standards and certifications being prepared • Some Member States with market-pull incentives • Platform under establishment	• 90 % of R&D at national level and no formal co-ordination between programmes • Technology transfer to industry and manufacturing issues poorly addressed and PV industry not competitive with Japan • Most Member States still lack incentives schemes for PV.
Clean fossil fuel	• Sleipner storage project in the North Sea is world-class. • International cooperation in Weyburn CO_2 Monitoring project in Canada • Good centres of excellence and networks • Technology platform under establishment • Good policy frameworks in several countries regarding cogeneration • EU legislation on cogeneration and CO_2 emission trading etc. • Launch of the 1.3 billion € Hypogen project • EU Commission and several Member States represented in CSLF and IPHE	• Low priority to short and medium-term clean fossil fuels technologies in FP6 • Fragmented R&D • R&D on gas turbines not followed by demonstrations in FP6 as in the USA • No capture technology manufacturers • Financing of Hypogen and technology choice not yet clarified • Still some uncertainty regarding CO_2 allowances and taxation. • No legal framework for CO_2 storage

<table>
<tr><th></th><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>Nuclear fission</td><td>• Strong basic nuclear R&D at EU level and in some Member States.
• Construction of a new, safer nuclear reactor (EPR) in Finland and France gives European industry a competitive advantage in new markets in China and other fast-developing countries.
• EU legislation proposed on nuclear safety and waste
• Long-lasting Euratom Treaty</td><td>• Public and political concern regarding nuclear power
• Very different Member State policies towards nuclear power
• Member States and the EU subject to two competing international fora on fission R&D</td></tr>
<tr><td>Nuclear fusion</td><td>• Well-established, well-functioning ERAnet in fusion, taking a lead in international R&D
• Spin-offs from fusion R&D
• Long-lasting Euratom Treaty</td><td>• Very long-term and resource-demanding research</td></tr>
<tr><th colspan="2">Opportunities</th><th>Threats</th></tr>
<tr><td colspan="2">• Make full use of a diversified set-up of market-pull and technology-push measures in energy efficiency and new cleaner, sustainable energy technologies such as biomass and biofuels, hydrogen & fuel cells, PV and others
• Promote coordination and cooperation between EU administrations
• Make full ERAs in key energy technology areas with necessary funds, commitments by industry and Member States
• Develop synergies between the Member States’ initiatives
• Strengthen international R&D and commercial relations with emerging markets for new energy technologies</td><td>• Continued fragmentation of EU energy R&D
• Public concern regarding some technologies (GMOs, nuclear)
• Competition from the USA and Japan and also from fast-developing low-income countries like China, India etc.</td></tr>
</table>

SWOT of Socio-economic Challenges and Europe's Scientific and Technological Base for Energy

Table 9. Summarised SWOT.

	Strengths	Weaknesses
Socio-economic challenges	• Diversified policies, including market-pull and technology-push measures • Ambitious targets for RES, RES-E, biofuels, CO_2 reductions and energy efficiency • Infrastructure investments to sustain/support a liberalised gas and electricity market • Relatively stable R&D nuclear energy at EU and Member State levels • Increasing share of renewable energy R&D	• Though ambitious, EU targets are not radical enough in light of the challenges of energy supply and CO_2emissions . • Implementation problems • No enforcement mechanisms, except for "common and cooperation" measures • Decreasing FP energy R&D • Decreasing EU-15 energy R&D and much less EU-15 energy R&D funds than Japan and less than the USA (1974-2002). • Political awareness on energy efficiency R&D, but in practice relatively low prioritisation compared to the USA • Unevenly distributed (and uncoordinated) renewable energy R&D • Outspoken distinction between new Member States and the old Member States in dedicated non-nuclear energy R&D programmes
S&T base	• Political ambition to create the European Research Area • Political awareness of opening national R&D programmes to other Member States • Technology Platforms established or under establishment in 3-4 major R&D areas • ERA in fusion • Strong scientific base in chemistry, materials science, energy systems, renewables, fuel cells, nuclear fission and fusion • Ambitious demonstration projects, including CUTE, HyCom, Hypogen, Sleipner storage, JET etc. • Leading industry in bioelectricity, steam reforming, PV components, EPR • Representation in international organisations (IPHE, CSLF etc.)	• Most energy R&D remains at Member State level, and R&D is not coordinated. • The resources allocated to energy R&D are insufficient to prepare Europe for the long-term challenges. • Technology transfer from science to industry is often poorly addressed (biomass, PV, clean fossil fuel, FC). • No coordinated market-pull policies for new energy technologies. • Unclarified financial set-up for new ambitious demonstration projects • Different Member State policies towards nuclear power.

	Opportunities	Threats
Socio-eco. challenges	• The EU has the possibility of fully using various market-pull and technology-push measures to address security of supply, climate change and environmental problems.	• Investment in energy is long-term business and the EU-25 may be too slow or ill prepared to address the challenges related to the growing dependence on imports of fossil fuels, climate change and environmental problems and economic growth.
S&T base	• Make fully use of a diversified set-up of market-pull and technology-push measures in energy efficiency and new, cleaner, sustainable energy technologies • Promote coordination and cooperation between EU administrations • Make full ERAs in key energy technology areas with necessary funds, commitments by industry and Member States • Develop synergies between Member State initiatives • Strengthen international R&D and commercial relations with emerging markets for new energy technologies	• Continued fragmentation of EU energy R&D • Public concern regarding some technologies (GMOs, nuclear) • Competition from the USA and Japan and also from fast-developing, low-income countries like China, India etc.

Availability of energy is a prerequisite for economic growth and welfare. Increasing energy consumption, liberalisation of the energy markets, security of energy supply and the need to take action on climate change and environmental matters are producing new challenges for the energy sector. The strategic goal of EU energy research is to develop sustainable energy systems and services for Europe.

Considering current trends, the outlook for the European energy situation is one of increasing consumption, increasing use of fossil fuels and a doubling in imports of fossil fuels. The EU’s response to this situation is diversified, combining market-pull and technology-push measures. Ambitious targets are set for renewables, electricity generated from renewables, biofuels, energy efficiency etc. But even such ambitious targets may not be sufficient to address the serious challenges ahead. Further, there are major implementation problems due to a lack of enforcement mechanisms. Another implication is the fact that market-pull measures are not coordinated across Member States.

Energy R&D funds have fallen at EU and also at Member State level over the years. The prioritisation of funds reflects history, and over the years, the funding for nuclear research has declined, and more funds are now allocated to non-nuclear research. There are major differences across the Member States reflecting energy policies and path dependency in energy R&D. In particular, there is a marked distinction between the new Member States and the old ones within the field of dedicated non-nuclear energy R&D programmes, and the challenges involved in setting up energy R&D programmes in the new Member States should not be underestimated. Energy efficiency R&D attracts considerable political awareness, but in practice this field is rather diffuse.

It is definitely a strength that there is a strong political commitment to creating a European Energy Research Area (EERA), and important steps have been taken to pave the way. These include (in addition to the instruments in the FPs) the efforts to make ERAnets and thereby opening up national and regional R&D programmes to other Member States, but also the establishment of technology platforms with key tasks in making strategic research and deployment agendas. Still, the impact of these measures remains to be seen.

There is a strong European base in fundamental science and technology areas of relevance to key energy technologies, and in some areas, ambitious experiments and demonstrations have been set up, all of which make European stakeholders attractive in international collaboration.

In some sectors, European industry is leading the way, but in general technology transfer from science to industry is not satisfactory and at least not competitive with the USA and other OECD countries.

Last but not least, the dedication of energy R&D and the associated resources are not sufficient to address the challenges ahead of us. Europe has some scope for making use of technology-push and market-pull measures. In particular, prospects are good for coherent research areas characterised by sufficient funds and commitment by industry and governments when combining R&D in energy efficiency and new cleaner sustainable energy technologies.

In conclusion, the recommendations made by the European Energy Research Area working Group (ERAWOG) certainly are key to making a European Energy Research Area (EERA) (European Commission, 2005g):

- Political commitment to solving environmental, economic and societal problems that energy research aims to address
- Long-term commitment of RD&D resources
- Commitment of all stakeholders to a set of strategic agendas and deployment strategies
- Access to public funding for expensive, high-risk, long-term projects but also to additional private-sector risk capital
- Availability of world-class energy research facilities at a European level
- Pooling of energy research intellectual resources
- Ability to carry out the necessary cross-cutting research, especially in materials science central to much energy research

Looking Ahead

When looking ahead, it is important to make transparent the key problems, questions and uncertainties related to the future energy situation:

Energy resources:

- How much fossil fuel (oil, gas, coal and unconventional sources such as tar sands and oil shale) can be recovered in the future and at what cost?
- What are the prospects for the use of carbon-neutral nuclear and renewable energy sources as well as the use of fossil fuels with carbon capture and storage?

Environmental impacts and other risks of energy consumption:

- How does the consumption of energy affect the environment, human health and the climate?
- What level of pollution can be accepted politically?
- How will perceptions about the environmental impact of energy consumption change in the future, and which policies will be implemented?

Economic development and social and lifestyle changes:

- How will the world's economy develop?
- By how much will the demand for energy services grow?
- How will the extraction and use of resources be distributed on a global scale?

Prospects for technological change:

- How much will current technologies improve, and which new technologies may become available in the future and at what cost?
- How will technological changes affect costs, energy service levels, energy efficiency, fuel choices and related environmental impacts of energy production and end-uses?
- What will be the impact of new technologies on energy system architecture?

Prospects for security of energy supply and national energy independence:

- Can countries and regions that now depend on energy imports increase national energy independence through use of domestic energy resources?

Prospects for more equal access to energy resources and for a more equal distribution of energy services:

- What are the prospects for economic growth in developing countries, and how will this affect energy trade, consumption patterns, energy prices and environmental impacts?

New innovative technologies will be a decisive factor in reducing dependence on oil and gas while also increasing the ability to meet international commitments to reducing the energy and transport sectors' environmental load. Key emerging technologies in this respect are efficient end-use technologies as well as new efficient technologies for energy production, distribution and storage.

In the energy foresight undertaken in various settings, some of the key problems and questions are used to develop different plausible energy scenarios against which R&D actions and roadmaps are tested. Below are examples of energy foresight in Europe (involving a foresight process with participation of various stakeholders and with a long-term view):

Energy Foresight – Sweden in Europe was initiated by The Royal Swedish Academy of Engineering Science (IVA) in 2002 and involved more than 100 experts who in during 2002 worked on four panels focusing on systems, users, structure and long-term issues (The Royal Swedish Academy, 2003). Some starting points:

- The time perspective was 20 years, with glimpses of 50 years.
- Transport, industry and built-up areas were three integrated parts
- Key generic technologies of importance to energy were: IT, new biology and material technology.
- Different views of climate changes, including ”The climate in focus” and ”The climate – one factor among others” scenarios.

EU 2050 – The climate in focus	**EU 2050 – The climate – one factor among others**
• Solar-based electricity (e.g. wind, PVs, bio) and hydrogen-powered FCs have a considerable and growing market share • A number of countries have replaced nuclear power after 60 years in operation. A new generation of nuclear power offers increased safety and a bridge to a solar and hydrogen-powered society. • Natural gas with CO_2 capture and storage is the dominant fossil fuel for electricity production. • A majority of vehicles have FCs running on hydrogen produced from natural gas with CO_2 carbon capture and from renewables. • Heating and cooling with natural gas and electricity.	• Solar-based electricity has a limited but growing market share. • Present nuclear power plants have been phased out after 40 years in operation. • Electricity production using natural gas and highly efficient coal-fired power plants with CO_2 capture. • Many vehicles use fossil fuels with a large influx of natural gas. Only vehicles without emissions are allowed in central parts of urban areas. • Heating and cooling by natural gas and electricity.

In addition to the two climate scenarios, four scenarios were developed focusing on different degrees of EU development and different levels of penetration of IT. Based on these different, plausible scenarios, a number of prioritised issues were selected:

1. Energy need – level and composition, including
   - More energy-efficient buildings – but larger spaces to heat or cool.
   - Integrated solutions and better logistics – but increased need for transport
   - More energy-efficient industrial processes – but an annual growth in population

2. Nuclear power replacements, including
   - Natural gas – one alternative
   - New nuclear power and renewable sources of energy are other alternatives
   - Fossil power can be environmentally adapted
   - The bridge to a solar and hydrogen society by means of natural gas and nuclear

3. Fossil fuel reduction within the transport sector, including
   - New vehicle technology and new fuels
   - Biofuels

Energy for Tomorrow. Powering the 21st Century was initiated by the British Department of Trade & Industry in the context of the Foresight Programme (www.foresight.gov.uk/; Department of Trade and Industry, 2001). It was carried out by the Energy Futures Task Force in close collaboration with regional foresight coordinators and others. Like the Swedish foresight, a scenarios approach was chosen to explore different plausible futures (with the time perspective of 2040) to gain insight into implications of different scenarios and to see beyond present concerns.

The four scenarios were:

- *World Markets*: a world defined by an emphasis on private consumption and highly developed and integrated world trading systems;
- *Provincial Enterprise*: a world of consumerist and short-termist values coupled with policy-making systems that assert national and regional concerns and priorities;
- *Global Sustainability*: a world in which social and ecological values are considered in economic decisions, and in which strong collective action through global institutions tackles environmental problems;
- *Local Stewardship*: a world where stronger national and regional governance allows social and ecological values to play a strong role in the development of markets and behaviour.

The challenges arising from the scenarios were Sustainable Development, R&D and Education and Training, to which the following key R&D themes and recommendations were addressed:

- Long-term R&D to begin now to determine how the UK can best move from an infrastructure based on relatively few, large plants to one with many, smaller generators that are geographically dispersed.
- R&D needs to be started and coordinated to ensure that the UK is able to manage the change from oil-based transport fuels. This includes ensuring an appropriate regulatory environment and enabling the UK to take a full part in international decision-making.
- A full re-examination must be undertaken of the nuclear power issue.

Other prospective energy projects include:

- Nordic Hydrogen Energy Foresight (www.h2foresight.info)
- The next 50 years: Four European energy futures (Bruggink, 2005)
- EurEnDel – European Energy Delphi (www.eurendel.net)
- Electricity Technology Roadmap, USA (www.epri.com)

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Appendix 1: Policies and Programmes of International Organisations

In the field of energy policy and energy technologies a substantial number of international collaboration bodies and councils exist at global level. Key international organisations are:

International Energy Agency (IEA)

The International Energy Agency (IEA) was established in November 1974 in response to the oil crisis as an autonomous intergovernmental entity within the Organisation for Economic Cooperation and Development (OECD) to ensure the energy security of industrialised nations (www.iea.org).

Under the Agreement on an International Energy Program (IEP), IEA Member countries commit themselves to holding emergency oil stocks equivalent to 90 days of net oil imports and to taking effective cooperative measures to meet any oil supply emergency. Over the long term, Members strive to reduce their vulnerability to disruptions of supply. Means to attain this objective include increased energy efficiency, conservation, and the development of coal, natural gas, nuclear power and renewable energy sources, with a strong emphasis on technology.

In 1993, IEA Members adopted Shared Goals that highlight the importance of ensuring the energy sector's contribution to sustainable economic development, social welfare and the protection of the environment. In addition, the formulation of energy policies should encourage free and open markets. The IEA is based in Paris and acts as a permanent secretariat to the Member countries, monitors the energy markets, organises the response to emergency situations and keeps energy and environmental policies and practices under constant review to encourage the use of best practices among Members and beyond. The IEA also promotes rational energy policies in a global context through cooperative relations and dialogue with non-Member countries, including major energy producers and consumers, and operates a permanent information system on the international energy market.

The 25 members are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the UK and the USA.

International Atomic Energy Agency (IAEA)
The IAEA is the world's centre of cooperation in the nuclear field (www.iaea.org). It was set up as the world's "Atoms for Peace" organisation in 1957 within the United Nations family. The Agency works with its Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies. In 2004, the IAEA has 124 Member States and has concluded safeguards with 148 countries.

As more countries mastered nuclear technology, concern deepened that they would sooner or later acquire nuclear weapons. There was growing support for international, legally binding, commitments and comprehensive safeguards to stop the further spread of nuclear weapons and to work towards their eventual elimination. In 1968, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was approved. It essentially freezes the number of declared nuclear weapon states at five (the USA, Russia, the UK, France and China).

In 1991, the discovery of Iraq's clandestine weapon programme sowed doubts about the adequacy of IAEA safeguards, but also led to steps to strengthen them. Today, new states have nuclear weapon programmes, including Pakistan, India and most probably also Israel. Libya planned to make a nuclear weapon programme, but never succeeded and in 2003 gave the IAEA access to all information and facilities. Major international concerns are now related to the Democratic People’s Republic of Korea (DPRK) and Iran.

International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

In 2001, following a Russian initiative, the INPRO was established within the framework of the IAEA and with the following IAEA Member States: Argentina, Armenia, Brazil, Bulgaria, Canada, Chile, France, the Netherlands, India, Indonesia, China, Pakistan, Russia, Switzerland, Spain, South Africa, Republic of Korea, the Czech Republic, Turkey, Germany and the EU Commission. The objective is to support the safe, sustainable, economic and proliferation-resistant use of nuclear technology to meet the global energy needs of the 21st century. Case studies for the assessment of INPRO methodology include: CAREM-X reactor (Argentina), Advanced Heavy Water Reactor (India), BN-800 reactor (Russia) and DUPIC Fuel Cycle (Republic of Korea), Reactor Cooled by Molten Salt (the Czech Republic) and High-temperature Gas-cooled Reactor (China) (Lauritzen et al., 2005).

Generation IV International Forum (GIF)
On the initiative of the USA, the Generation IV International Forum (GIF) was founded in 2001 by 10 countries – Argentina, Brazil, Canada, Euratom, France, Japan, Republic of Korea, Republic of South Africa, Switzerland, the UK and the USA. GIF lays the groundwork for the fourth-generation nuclear reactor – Generation IV. Nuclear power plant technology has evolved as three distinct design generations – I. prototypes, II. current operating plants and III. advanced reactors. Generation IV must be licensed, constructed and operated in a manner that will provide a competitively priced supply of energy. They must consider an optimum use of natural resources, while addressing nuclear safety, waste and proliferation resistance and public perception concerns of the countries in which those systems are deployed. Because the next generation of nuclear energy systems will address needed areas of improvement and offer great potential, many countries share a common interest in advanced R&D. Such development will benefit from the identification and promising research areas and collaborative efforts that should be explored by the international research committee.

The United Nations Framework Convention on Climate Change (UNFCCC)

The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenges posed by climate change. It recognises that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other heat-trapping gases (www.unfccc.int). Under the Convention governments:

- gather and share information on greenhouse gas emissions, national policies and best practices;
- launch national strategies for addressing greenhouse emissions and adapting to expected impacts, including the provision of financial and technological support for developing countries;
- cooperate in preparing for adaptation to the impacts of climate change.

The 1997 Kyoto Protocol shares the Convention's objective, principles and institutions, but significantly strengthens the Convention by committing Annex I Parties to individual, legally binding targets to limit or reduce their greenhouse gas emissions. Only Parties to the Convention that have also become Parties to the Protocol, however (that is, by ratifying, accepting, approving, or acceding to it), will be bound by the Protocol's commitments. The individual targets for Annex I Parties are listed in the Kyoto Protocol's Annex B. These add up to a total cut in greenhouse gas emissions of at least 5 % from 1990 levels in the commitment period 2008-2012. With the Russian ratification in November 2004, the Protocol has now come into force.

Carbon Sequestration Leadership Forum (CSLF)

The Carbon Sequestration Leadership Forum is an international climate change initiative that is focused on developing improved, cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage. The purpose of the CSLF is to make these technologies broadly available internationally; and to identify and address wider issues relating to carbon capture and storage. This could include promoting the appropriate technical, political and regulatory environments for the development of such technology.

The CSLF charter was signed in June 2003. The 17 members are Australia, Brazil, Canada, China, Columbia, France, Germany, India, Italy, Japan, Mexico, Norway, Russia, South Africa, the UK, the USA and the European Commission. The charter will stay in effect for 10 years and establishes a broad outline for cooperation for the purpose of facilitating the development of cost-effective techniques for the capture and safe long-term storage of carbon dioxide (CO_2), while making these technologies available internationally. While several large-scale international CO_2 sequestration projects are under way, this first-ever ministerial-level sequestration forum underlines the new importance given to international cooperation (www.cslforum.org).

International Partnership for the Hydrogen Economy (IPHE)

The International Partnership for the Hydrogen Economy (IPHE) was established in November 2003 on the initiative of the USA following the establishment of the Carbon Sequestration Leadership Forum (CSLF) in June 2003. The following countries are members: Australia, Brazil, Canada, China, France, Germany, Iceland, India, Italy, Japan, Norway, Republic of Korea, Russian Federation, the UK, the USA and the European Commission.

The IPHE aims to serve as a mechanism for organising and implementing effective, efficient and focused international research, development, demonstration and commercial utilisation activities related to hydrogen and fuel cell technologies. It also provides a forum for advancing policies and common codes and standards that can accelerate the cost-effective transition to a global hydrogen economy to enhance energy security and environmental protection. It has the following functions (www.iphe.net):

- Identifies and promotes potential areas of bilateral and multilateral collaboration on hydrogen and fuel cell technologies;
- Analyses and recommends priorities for R&D, demonstration and commercial utilisation of hydrogen technologies and equipment;
- Analyses and develops policy recommendations on technical guidance, including common codes, standards and regulations, to advance hydrogen and fuel cell technology development, demonstration and commercial use;
- Fosters the implementation of large-scale, long-term public-private cooperation to advance hydrogen and fuel cell technology and infrastructure research, development, demonstration and commercial use, in accordance with Partner priorities;
- Coordinates and leverages resources to advance bilateral and multilateral cooperation in hydrogen and fuel cell technology research, development, demonstration and commercial utilisation; and
- Addresses emerging technical, financial, legal, market, socioeconomic, environmental, and policy issues and opportunities related to hydrogen and fuel cell technology that are not currently being addressed elsewhere.

World Energy Council (WEC)

The World Energy Council (WEC) is the foremost global multi-energy organisation in the world today. WEC has Member Committees in over 90 countries, including most of the largest energy-producing and energy-consuming countries. The 81-year-old organisation covers all types of energy, including coal, oil, natural gas, nuclear, hydro, and renewables, and is UN-accredited, non-governmental, non-commercial and non-aligned and located in London (www.worldenergy.org).

WEC's Mission: *"To promote the sustainable supply and use of energy for the greatest benefit of all people"*. The objects are to promote the sustainable supply and use of energy for the greatest benefit of all people, by:

a. collecting data about and undertaking and promoting research into the means of supplying and using energy having, in the short and long term, the greatest social benefit and the least harmful impact on the natural environment, and publishing or otherwise disseminating the useful results of such research;

b. undertaking actions, including but not limited to the holding of congresses, workshops and seminars, to facilitate such supply and use of energy; and

c. collaborating with other organisations in the energy sector with compatible goals.

World Council for Renewable Energy (WRCE)

The World Council for Renewable Energy was founded in Berlin in 2001 by a group of non-governmental organisations working in the field of renewable energy. It is headed by a chairman committee with five members from five continents. The present secretariat is with the European Association for Renewable Energies (EUROSOLAR).

The WREC's mission is to bring renewable energy into the mainstream of world economy and lifestyle. It seeks to convince the global opinion of the potentials of renewable energy while showing the undesirable developments, the dangers, hidden costs and the damage to civilisation, caused by conventional energy supply. For achieving these objectives, WREC uses the means of information, agenda setting and networking.

Mission

To promote an innovative and environmentally sustainable technological development within the areas of energy, industrial technology and bioproduction through research, innovation and advisory services.

Vision

Risø's research **shall extend the boundaries** for the understanding of nature's processes and interactions right down to the molecular nanoscale.

The results obtained shall **set new trends** for the development of sustainable technologies within the fields of energy, industrial technology and biotechnology.

The efforts made **shall benefit** Danish society and lead to the development of new multi-billion industries.