EuCheMS

Chemistry and Energy

The role of the chemical sciences in European energy policy

April 2008






Key recommendations

- **Carbon capture and storage** (CCS) demonstration projects are required on a large scale. Efficient capture and sequestration of carbon dioxide from fossil fuel power generation is necessary to provide low-carbon electricity.

- **Waste minimisation,** recycling and heat recovery should be taken into consideration during product design. It is important that comprehensive cradle to grave analysis (Life Cycle Analysis) is carried out on energy options to ensure that a solution to a problem does not simply shift the environmental burden up or downstream. Chemical sciences should help to develop new materials and products that are energy efficient and promote sustainable use of resources.

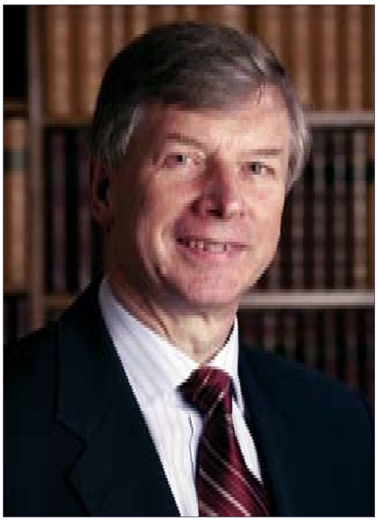
- **Renewable energy sources** that are cost effective and highly efficient can be established with a significant contribution by the chemical sciences. Research into more efficient and less expensive materials to construct systems for solar energy conversion into heat and electricity are needed, as well as research into improved feedstock conversion and lightweight, durable materials and coatings for turbines.

- **Energy storage and batteries** have become a central issue for a number of technologies, including electric and hybrid electric vehicles and renewable energy sources. Chemical sciences need to make advances in the development of new electrode materials and new electrolytes, in order to improve the energy and power density and performance of these devices.

- **Nuclear power** continues to be provided within the European Union, and chemical science needs to address the entire nuclear fuel cycle, including geological burial, to improve efficiency, safety and security.

- **Engagement with the public** and the media by chemical scientists is essential if we are to steer consumer behaviour towards efficient use of energy. Chemical scientists should lead by example, providing clear and appropriate evidence-based, unbiased information to the public about current issues such as climate change and sustainable energy technologies.

- **Effective innovation** systems must be in place to promote knowledge transfer, and provide mechanisms for bringing technologies to market. A long-term framework is required that supports and encourages industry to change towards more sustainable manufacturing processes. This will require greater transparency in economics, pricing and policy and better communication between government, industry and the public.



Foreword

Energy is a vital part of our daily lives. Without it, we cannot heat our homes, power our businesses or use transport. This timely report outlines how the chemical sciences can provide the technologies, infrastructure and skills needed to meet the ambitious energy targets set out by the European Union. Chemistry can rise to this challenge because chemical and molecular scientists have a unique understanding of the fundamentals underlying new developments in the way energy is generated and used.

This report focuses on presenting the state of play in the areas of power generation, heating, energy efficiency and transportation. It addresses a range of supporting technologies including carbon capture and storage, life cycle analysis and energy storage.

The discussion surrounding energy's key issues are presented in this document. How can technologies be employed to capture and store CO_2? How can chemical sciences make renewable power generation technologies more competitive with fossil fuels? What are the implications for nuclear energy? Is there a way to mimic photosynthesis to produce fuel sources and to recycle CO_2 from the atmosphere? What is the potential for biofuels and hydrogen fuel cells in transport? How can the chemical sciences help to build and run our homes with greater energy efficiency?

Over the next fifty years Europe is due to implement key actions for developing sustainable energy systems and managing the transition from the prevalent use of fossil fuels to a wider mix of energy sources. This report is part of an ongoing campaign by EuCheMS to highlight the enormous potential chemical sciences provide in delivering the right technologies to meet such challenges.

Richard Pike
Chairman, EuCheMS Working Party on Chemistry and Energy
Chief Executive, Royal Society of Chemistry

Purpose of this document

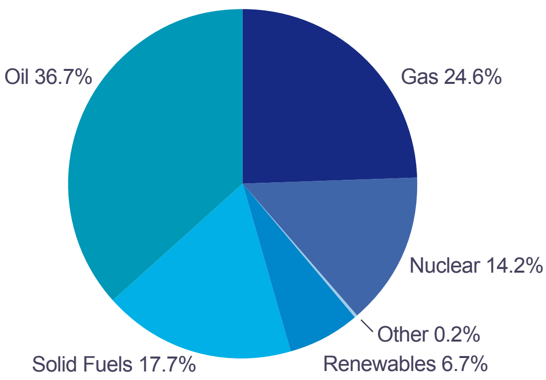
This report is intended to provide guidance to policy makers and funding bodies on the challenges and key priority areas in European energy policy. We consider that the chemical sciences can provide the technologies, infrastructure, skills and stakeholder engagement needed to meet the ambitious targets set out by the European Union (EU). The report focuses on presenting sound scientific evidence to support its key recommendations in the areas of power generation, energy efficiency and transportation.

The European Association for Chemical and Molecular Sciences (EuCheMS) is a non-profit-making organisation. Its object is to promote co-operation in Europe between non-profit-making scientific and technical societies in the field of chemistry and molecular sciences. EuCheMS provides a powerful single voice for chemists and the chemical sciences in Europe through its activities and development of policy. The organisation can draw upon significant resources, having 50 member societies which in total represent some 150,000 individual chemists in academia, industry and government in over 35 countries across Europe.

Background

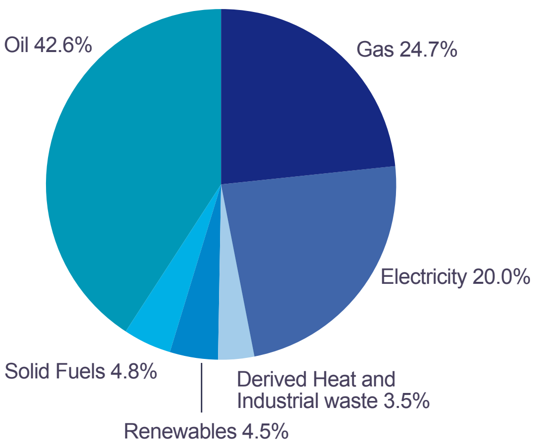
Over the next fifty years, Europe is due to implement key actions for developing sustainable energy systems and managing the transition from the prevalent usage of fossil fuels to a wider mix of energy sources. Globally, fossil fuels currently account for more than 80% of energy demand with the remainder met by a mixture of nuclear (6%), hydro (2%) and other renewable energy sources (12%) including biomass combustion which represents two thirds of the latter figure. Concerns over energy security and climate change need to be the drivers towards responsible and rational energy demand and energy efficient technologies for heating, lighting, transport, power generation and information management. Comparable EU data are shown for gross and final (net) consumption (below, left).

Gross Consumption - EU27 by Fuel (Year 2005)



Total approximately 1750 Million tonne oil equivalent (Mtoe)

Final Energy Consumption - EU27 by Fuel (Year 2005)



Total approximately 1150 Mtoe

Adapted from Energy and Transport in Figures 2007, Part 2: Energy[1]

The EU is leading the world in addressing perhaps the greatest challenges of the 21st century: energy and climate change. In January 2007, "A European Strategy for Sustainable, Competitive and Secure Energy" was announced. The European Commission proposed several key targets for 2020, including:

- a 20% reduction in EU greenhouse gas emissions, as compared with 1990 levels, or 30% if other developed nations agree to take similar action;
- obtaining 20% of all energy from renewables;
- saving 20% of energy through improvements to energy efficiency;
- increased use of biofuels, to at least 10% of all fuel used for transport.

The transition process will require considerable ingenuity from chemists, other scientists and engineers, who will develop sustainable energy systems and also find more efficient ways of producing, refining and consuming fossil fuels.

Power generation

The future energy mix in Europe will be a derived from a combination of fossil fuels, renewables and nuclear (with regional variations in composition). Statistics show that the gross consumption of fuel is approximately 1750 Mtoe, which is about one-and-a-half times the final energy consumption of approximately 1150 Mtoe. This means that nearly one third of energy is lost during the conversion of fuels or during the transport of fuel to the end-consumer. It is therefore important that power is generated in the most efficient way and that transmission losses are minimised. This is the case whether electricity is generated in a large power plant, or locally through distributed generation. Chemical scientists will play a key role in developing the next generation high temperature superconducting materials that will reduce losses during electricity transmission. Solving these issues could have a huge potential to reduce the amount of energy the EU has to import to meet its energy demands.

Renewables

Currently, renewable sources are considered to be water (hydroelectric, wave, tidal), wind, sun (thermal and photovoltaics), biomasses and earth (geothermal). Some of these, such as wind power, are available intermittently and often in remote locations. As a consequence of this, the transmission and distribution network needs updating, which will require significant capital investment. Energy storage for intermittent sources of renewable power is a key research and development challenge. For renewable power sites operated in remote and harsh conditions, (e.g. for offshore wind, wave and tidal power) there is a need for coatings, materials and lubricants that enhance efficiency and operational lifetime with reduced cost.

In theory, solar power has the potential to provide all or a significant proportion of Europe's electricity needs. Current technology is moving towards converting sunlight into electricity with an efficiency of around 20%. The key challenges are to reduce the cost and increase the efficiency of solar technology. This could be achieved through improvements to design and manufacture and development of the next generation of technology, e.g. biological methods of harvesting and storing energy from light. Europe has a strong and vibrant research base in this area, particularly in understanding and mimicking photosynthesis systems and in dye-sensitised and organic solar cells that can be used as coatings on windows and construction materials. Ideally, it will become routine to integrate solar power cells into building materials, such as roof tiles and windows, and couple them to energy storage and low energy devices.

The need for energy storage will increase significantly with a rise in the proportion of renewable energy generation technologies, as most of these sources are intermittent in their supply. Energy storage is not only essential to balance intermittent supply and consumer demand; it also has an important role in energy trading since energy may be stored and then returned to the grid at a higher value. Other important issues are security and quality of supply. Improved battery technology is one option but significant increases in storage density will be required. Another option is to use the excess electricity to produce hydrogen, although as discussed later, there are issues associated with producing, storing and transporting hydrogen.

Clean fossil power

Fossil fuels will continue to contribute to power generation. To develop a clean option for fossil fuel power stations, carbon dioxide must be captured and stored permanently or recycled by developing a reliable CO_2 - based chemistry options. "Clean technologies" also minimise emissions of NOx, SOx, CO, volatile organic compounds, other micro-pollutants and fine particulates. If the economics are favourable there is considerable potential for Europe to export carbon capture and storage (CCS) technologies.

Support must be provided for organisations developing CCS technologies and for research projects that aim to use carbon dioxide as a potential feedstock for synthesis. Organisations that are developing CCS technology will need EU or local support to build demonstration plants. Working CCS technology should be adopted in industries where fossil fuels are heavily used and CO_2 emissions are high. It is also critical that an EU emissions trading scheme (or equivalent) is continued in order to provide a market incentive for removing CO_2. Substantial research and development is required before CCS is technologically and economically viable. Developments are needed in the fields of materials, sensors, controls, combustion chemistry, chemical process modelling and pollution mitigation. These will enable the latest developments in clean fossil technologies to be implemented at full scale. These challenges include:

- chemically converting large quantities of CO_2 into commercially useful chemicals and fuels;
- developing efficient and appropriate systems to capture CO_2 on various scales;
- identifying, characterising, monitoring and demonstrating sites for CO_2 storage.

Artificial photosynthesis is an emerging research field that attempts to replicate the natural process of photosynthesis, converting sunlight, water and carbon dioxide into carbohydrates and oxygen. The potential of artificial photosynthesis is enormous as it offers a route to sustainable fuel production and also potentially to a process that removes carbon dioxide from the atmosphere to create useful products.

Nuclear power

Nuclear power is a contentious issue in Europe. On the positive side it is a proven, low-carbon technology. On the negative side it gives rise to long-lived nuclear waste that is costly to dispose of properly and there is a risk of proliferation, radioactive pollution, terrorism and cancer clusters.

Regardless of whether new nuclear build occurs, many EU states already have a legacy of nuclear waste that must be managed. Deep geological repositories are the preferred scientific solution to achieve safe long-term disposal. The chemical sciences are essential for packaging and storing nuclear waste and in ensuring that the environment safely contains radionuclides. Safe transportation of radioactive material is vital.

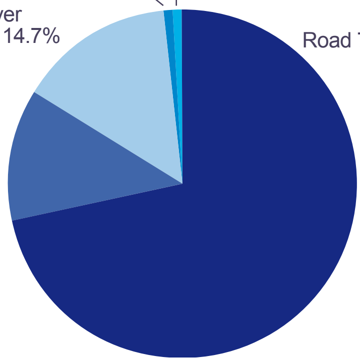
Nuclear fusion

The decision to site the International Thermonuclear Experimental Reactor (ITER) fusion reactor facility within Europe is welcomed. There are many challenges in developing safe, reliable and economic fusion power. The expertise of chemical scientists will be particularly important in designing materials that are capable of withstanding the extreme and unique conditions (high temperatures and neutron flux) of a fusion reactor.

Transport

The following charts place transport (27.4%) within the wider context of EU carbon dioxide emissions (below) and their specific source (right).

CO_2 Emissions and Transport - EU27 by Sector (Year 2005)

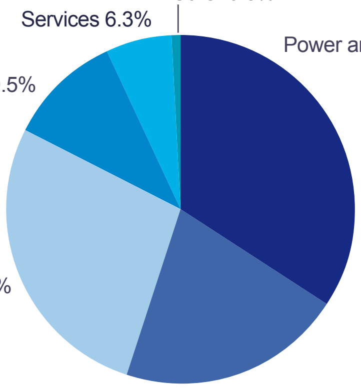


CO_2 emissions transport = 1247.9 Million tonnes CO_2 equivalent

Adapted from Energy and Transport in Figures 2007, Part 2: Energy[1]

Transport contributes significantly to the overall greenhouse gas emissions within the EU. As a result, there is a need to develop new technologies that create less pollution. The chemical sciences are pivotal in the development of systems that improve fuel and exhaust systems in vehicles. This has been demonstrated through the development of unleaded petrol (eradicating harmful lead additives), detergent additives (that increase fuel economy and engine lifetime), oxygenated fuels (that improve fuel efficiency) and catalytic converters (to reduce carbon monoxide, volatile organic compounds and nitrogen oxide emissions). Vehicle performance can be considerably improved by using lighter construction materials to reduce weight. The challenge to polymer and synthetic chemists is to create new structural materials and designs that radically reduce vehicle weight without compromising safety. In addition to that, improvements in efficiency could be made by developing more advanced low-friction tyres.

CO_2 Emissions - EU27 by Sector (Year 2005)



CO_2 emissions total = 4554.4 Million tonnes CO_2 equivalent

Biofuels

First-generation biofuels (bioethanol derived from starch/sugar crops or biodiesel derived from vegetable/animal oils) are already a mature technology. There are certain technological advances that could improve production efficiency. It is also important to exploit secondary products accompanying the production of biofuels to add value to the production of these fuels. For example, the huge amount of glycerol produced from the transesterification of vegetable oils for biodiesel should be transformed into useful products or to efficient energy sources such as hydrogen or valuable chemicals. This is a specific goal for current chemical research.

Second-generation biofuels that are derived from lignocellulosic biomass (such as cereal straw, trees, waste paper, etc) offer far greater potential for reduced cost and environmental impact compared with first generation biofuels. Furthermore, second generation biofuels do not necessarily compete with food production, unlike first generation biofuels. However there are a number of key technological barriers that must be overcome before second generation biofuels are realised. It is anticipated that if adequate funding and effort is applied to second generation biofuels then full commercial operations should be available by 2015. However, biofuels alone cannot mitigate the environmental impact of transportation, though second generation biofuels can play a significant role alongside other measures. In both food and biofuel production the chemical sciences are developing agrochemicals that increase biomass production whilst minimising environmental impact.

Hybrid and electric vehicles

Recently, hybrid vehicles have been introduced to the market place. Further improvements to hybrid vehicles will require lightweight construction materials, efficient low emission engines and improved battery or alternative energy storage technology. Energy storage is a key issue to which chemists and materials scientists have much to contribute. All of these issues are equally applicable to electric vehicles.

Hydrogen fuel cell

According to the European Technology Platform for Hydrogen and Fuel Cells (HFC), fuel cell applications will cover transport and also fixed installations. It is unlikely that full commercial development of hydrogen for transport will occur before 2020. There are still issues that have to be carefully addressed before full commercialisation can be implemented. The development of materials for hydrogen storage is a key challenge, particularly for automotive applications. New materials (metallo-organic frameworks, covalent organic frameworks, carbon and inorganic nanotubes, clathrates, aminoboranes) are currently being investigated to achieve significant hydrogen storage levels. For example, the US Department of Energy target for hydrogen storage is 6% of storage system weight by 2010 and 9% by 2015. The development of new electrocatalysts and solid polymer electrolytes is crucial for increasing fuel cell performance, improving robustness, enhancing flexibility in fuel composition and reducing production costs. Reduction or complete removal of precious metals, particularly platinum, is another important issue for research and development in order to improve fuel cell technology. Hydrogen production from biomass (e.g. via gasification process or via bacteria or algae capable of digesting domestic and agricultural wastes) or solar energy sources (e.g. using artificial photosynthesis and photovoltaic energy) could be viable options.

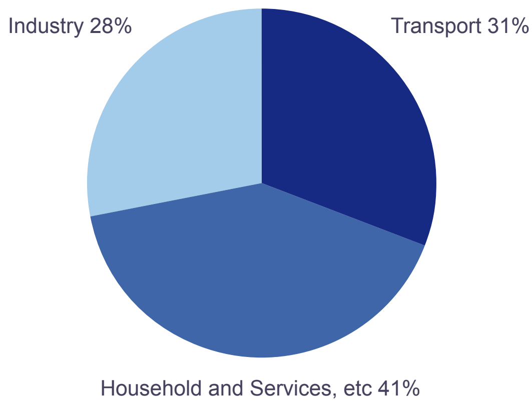
Air travel

Air transport is receiving increased attention because of environmental concerns linked to CO_2 emissions, air quality and noise. Further atmospheric chemistry research into the impact of aircraft emissions in the upper troposphere is required. Reducing aircraft weight will increase fuel economy and reduce emissions. Embedded sensors and controls in intelligent gas turbine engines could reduce noise, emissions and costs through more effective diagnosis and maintenance processes. New materials are required e.g. low-cost composites, corrosion and damage resistant alloys and smart materials to reduce costs across the entire product life-cycle. These could also reduce travel time. Advanced coatings for the next generation of gas turbine engines are required for improved fuel efficiency and emission reduction. Biofuels could also assist in reducing the environmental impact of aviation. Multidisciplinary teams of chemists, materials scientists and engineers are needed to develop viable solutions.

Domestic living

The chart below summarises the end-use distribution of energy. It shows that a large part of energy is consumed in the domestic sector. Domestic energy efficiency measures can therefore play a significant part in meeting European carbon reduction targets.

Final Energy Cosumption - EU27 (Year 2005)



Total is approximately 1150 Mtoe

Adapted from Energy and Transport in Figures 2007, Part 2: Energy[1]

The European Technology Platform for Sustainable Chemistry (SusChem) is examining the home as a self sufficient energy provider and also as an eco-efficient environment. Research should focus on superior solar power to maximise cost effective energy collection using silicon and conjugated polymer alternatives for the home environment. This needs to be combined with new solar panel production approaches, hybrid materials and new electrodes. Smart coatings to help regulate internal temperatures are needed for windows. The ideal window would be heat reflecting on a hot day to prevent solar radiation overheating the interior of a building, but would be heat insulating on a cold day to prevent heat escaping. There is considerable scope to develop environmentally benign and highly efficient insulating materials that control both temperature and humidity. These include aerogel nanofoams potentially obtained by recycling waste and by-products. Uptake of novel insulation methods should be encouraged for all homes through incentives.

Domestic appliances that are energy efficient and that do not have a stand-by mode should be encouraged. Efficient lighting systems such as organic light emitting diodes (OLED) can help reduce appliance energy usage. Energy saving light bulbs are becoming more popular but more could be done to encourage consumers to use them.

Domestic water, waste treatment and recycling are key areas where significant energy savings can be made. Advances in (bio-)catalytic chemistry will lead to more efficient processes for water remediation and treatment. For example, catalysis and nanotechnology could be combined to treat water or sewage in the sewage system. In mixed domestic waste, analytical chemistry is critical in identifying and segregating different waste types. Polymer and catalytic chemistry is essential in degrading plastics to make high quality recycled or even new products. Chemists and biochemists are working hard to deliver the next generation of plastics that are made from renewable resources and are biodegradable.

Cities and infrastructure

Heating and transport are major users of energy. An integrated approach to energy supply and transport infrastructure is required for cities and other large settlements. Decentralising power sources would result in minimal electrical losses and also decrease over-reliance on single sources. An electricity economy should be encouraged, particularly to replace vehicle fuel and gas for central heating. Electricity should be generated from non-fossil fuel sources. A decentralised electricity economy generated from renewable sources would reduce carbon emissions and inner city vehicle pollution.

In addition, transport infrastructure and accessibility in many cities can be improved to ease traffic congestion and encourage people to use public transport services.

Oil and chemical industry

There is a challenge for the chemical sciences to maximise the yield of oil extraction from global reserves. Subsequent refining of the crude oil offers further challenges; improved catalysts are needed to increase process efficiency, reduce energy and produce cleaner products such as ultra-low sulphur diesel. Research and development of efficient alternatives such as oxidative desulfurisation and conventional hydrodesulfurisation, should be encouraged. There is also a need to develop lower energy processes to replace distillation, such as membrane separation. Collaboration on CCS will be essential.

The chemical industry can achieve significant energy reductions through the use of intensive high-throughput processing, novel reactor design, micro-reactors, advanced separation technologies, more selective (bio-)catalysts, atom economical reactions, less energy-intensive processes, alternative energy sources (such as light) and alternative feedstocks. Chemical scientists are involved in advanced manufactured components for high efficiency products and many large European companies are embracing these technologies.

The Future

A global vision and world-wide leadership are essential to tackling energy and climate change issues. The Stern Report recommends better engagement between scientists, politicians and economists. Governments and the public are often more influenced by arguments for change based on economic reasoning than scientific information.

Diversification of energy supply and sources should be encouraged; renewable and sustainable energy sources are a solution to the EU's over-reliance on fossil fuels. By adopting more environmentally friendly and renewable energy sources we can mitigate some of the impacts of climate change and ensure energy sustainability for future generations.

Endnotes

1 http://ec.europa.eu/dgs/energy_transport/figures/pocketbook/2007_en.htm

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