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Transition to a sustainable energy system for Europe

The R&D perspective

A summary report by the Advisory Group on Energy

EUR 22394

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Transition to a sustainable energy system for Europe

The R&D perspective

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Preface

The Advisory Group on Energy (AGE) was appointed by the Commissioner for Research to provide independent external expert advice to the European Commission on energy R&D within the 6th Framework Programme.

This report is the fourth and last in a series by the AGE to be published by the Commission. In 2005, the first of two volumes examining R&D priorities across a range of important energy technologies was published (ref. 10), as the outcome of an AGE working group chaired by Prof Alfred Voss. In the same year, a report on the organisation and management of European energy R&D was published (ref. 12), as the outcome of a working group chaired by Dr Heather Greer. In June 2006, the second volume examining R&D priorities across those technology fields not addressed previously was adopted by the AGE for publication (ref. 7). It integrates the recommendations of a series of AGE working groups chaired by Mr Roger Ballay, Dr Niels Busch, and Prof Gerhard Faninger. In June 2006, this report on strategic energy technology priorities was also adopted by the AGE.

This report is written against the context of the European Commission's recently published Green Paper on a shared energy policy for Europe. The Green Paper proposes the development of a strategic energy technology plan for Europe, with the three objectives of sustainability, competitiveness, and security of supply. This report is intended to provide an input to that strategic planning process, by providing an independent opinion from the perspective of energy technology research and development. It is, in effect, the result of four and half years of close collaboration between the members of the AGE, involving discussions within the AGE at regular meetings in Brussels, and intensive electronic communications between the AGE members over a twelve month period. It is thus a consensual report from the AGE.

The AGE wishes to express its gratitude to the European Commission for its active support for its work over the four and a half year period. In particular, thanks are due to Mr Frederick Mariën, Mr Odisseas Panopoulos and Mr Michel Poireau for their assistance, advice and inputs to the AGE's work. We would also like to record our thanks to Ms Carla Velasco Martins for her administrative assistance.

There is a common misconception that the energy technologies needed for a more sustainable energy system for Europe are already available. This is simply not the case: while progress has been made, many of the technologies we need still require years – and in some cases decades – of further R&D before they can compete effectively in the market. Furthermore, there are many technology options, but it remains unclear as to which of these will eventually penetrate the market and gain significant share. Progressing the sustainability objective is a matter requiring strong public support, both in funding and in long term commitment. The AGE's main concern is that, without adequate funding and commitment, the necessary progress will not be made. We hope to emphasise to European decision makers the importance to society of the task, and to urge leaders to encourage open debate on the technology options available and the benefits and inevitable trade-offs that will be involved. We hope this report will be useful in advancing such a debate.

Dr Heather Greer
Vice Chair

Prof Peter Lund
Chair

Energy for Europe: the challenge

The European Commission's recent Green Paper (ref. 1) on a shared European energy strategy proposes three main objectives as a framework for such a strategy:

Sustainability
- Developing competitive renewable sources of energy and other low carbon energy sources and carriers, particularly alternative transport fuels
- Curbing energy demand within Europe
- Leading global efforts to halt climate change and improve local air quality

Competitiveness
- Ensuring that energy market opening brings benefits to consumers and the economy as a whole, stimulating investment in clean energy production and energy efficiency
- Mitigating the impact of higher international energy prices on the EU economy and its citizens
- Keeping Europe at the cutting edge of energy technologies

Security of supply - Tackling the EU's rising dependence on imported energy through:
- An integrated approach - reducing demand, diversifying the EU's energy mix with greater use of competitive indigenous and renewable energy
- Creating the framework which will stimulate adequate investments to meet growing energy demand
- Better equipping the EU to cope with emergencies
- Improving the conditions for European companies seeking access to global resources
- Making sure that all citizens and business have access to energy (ref. 1)

The Green Paper proposes the introduction of a regular Strategic EU Energy Review, and the development of an Action Plan on Energy Efficiency, a Renewable Energy Road Map, a Strategic Energy Technology Plan, and a common external energy policy, all of which will be developed as quickly as possible. It recognises that "Europe must act urgently: it takes many years to bring innovation on stream in the energy sector".

There is indeed a need for urgency. Much, if not all, of the proposed framework requires an extensive programme of energy R&D – this in an environment of uncertainty where market actors are reluctant to invest in long term research or in risky technologies. Widespread market deployment of many of the mainstream energy technologies currently under development will happen over decades rather than years. Nonetheless, Europe has a long tradition of innovation in energy technology, and this represents an important strength at a crucial time.

This report from the Advisory Group on Energy (AGE) presents an energy technology R&D perspective, reviewing the R&D needs and priorities, while bearing in mind the framework proposed by the Green Paper.

The European energy system in transition: key drivers

There are powerful drivers of change:

- Europe's dependence on **imported oil and natural gas** is high and rising. Quite apart from the uncertainties and risks associated with the geopolitics of oil and gas supply – and there is no reason to believe that these will diminish – global production of oil will most probably soon reach a plateau, before entering a period of inevitable decline. Improved oil recovery techniques and exploitation of non-conventional sources of supply may prolong the plateau, but are unlikely to delay its onset. Natural gas will peak two to three decades later. And there is rapidly increasing global competition for the imported oil and gas resources on which Europe depends. Whatever the uncertainties, the risks are so great that the precautionary principle must apply, and thus the message is clear: *we must greatly reduce our dependence on oil over the short to mid term.*

- **Atmospheric concentrations of CO_2** have increased from 280 ppmv to 370 ppmv since pre-industrial revolution times, and the rate of growth is accelerating. As the Intergovernmental Panel on Climate Change has pointed out (ref. 2), "stabilisation of atmospheric concentrations of CO_2 at any level requires eventual reduction of global CO_2 net emissions to a small fraction of the current level". *Efforts to achieve major cuts in energy-related CO_2 emissions must be accelerated immediately.*

- Large components of our **energy systems** have life cycles of greater than 50 years, and new, capital-intensive plant and infrastructure of necessity involves designs with even longer planned life cycles. With some energy technologies for the future, the necessary R&D may add several more decades; thus, decisions taken now may shape the world for up to a century or more. *Strong policy measures and frameworks are urgently needed to encourage long term investments that will genuinely contribute to addressing the strategic challenges we face.*

- **Economic considerations** affect the mix of energy technologies and the penetration of new ones, the relative prices of competing technologies directly affecting the speed at which the mix changes. Full integration of the external costs of energy would be essential if the mix is to change in the desired ways, even if some external costs are quantitatively unknown (as in climate change), and have to be fixed by political decisions. *Stronger, if possible common, public interventions are needed, both to support the necessary energy R&D and to influence the relative costs to consumers of more sustainable energy technologies.*

- **The market for energy technologies** is global and is very large[1]. *Europe must build its strengths if it is to compete successfully in this market; energy R&D is an essential component, requiring sizeable long term investments by industry and from public funds.*

Europe cannot go it alone. Our problems are shared with the rest of the world (and our energy problems must not be solved to the detriment of other pressing problems such as the availability of food and water for a growing world population). And some of the challenges are so great that they demand an international effort. *Europe must play an equal partnership role with others in addressing many of today's energy problems; in some cases, Europe can take the lead.*

[1] *The estimated global market to 2030 is some € 16 trillion. Following an accelerated low-emissions route would greatly increase this figure.*

Strategic technology issues

Energy for transport

The transport sector accounts for more than 30% of total energy consumption in the EU, with 98% dependence on fossil fuels and a rising energy demand; it is therefore important to reduce the dependence of this sector on oil-based fuels, though it must be borne in mind that it is easier and cheaper to replace hydrocarbons in other sectors than in transport. Table I summarises the main currently known transport technology options for reducing both oil consumption and CO_2 emissions.

There are immediate or short term steps that would lead to substantial reductions in consumption and emissions. There are technologies that are already available. Smaller vehicles and engine sizes, the most efficient ICEs (both petrol and diesel since these technologies are likely to follow similar development paths), hybrid electric drive vehicles, bio-diesel and bio-ethanol, smart traffic management systems, transport mode switching, and changed driver behaviour would, if encouraged strongly by public policy and favourable life cycle costs, make a considerable difference to emissions and consumption. *The many available options for reducing transport energy consumption should be strongly encouraged by public policy. There would be advantages in seeking a common European approach to this. Ongoing support for R&D is justified.*

Also needed in the short term is a well-developed European biocrop infrastructure. Although there are R&D needs in all aspects of biocrop production and conversion, existing technologies for bio-diesel and bio-ethanol are already penetrating the market, albeit to some extent through tax subsidies. The Biofuels Research Advisory Council's vision (ref. 3) is of biofuels contributing up to 25% of transport fuel needs by 2030 (though biocrops cannot be grown at the expense of food production). However, *urgent steps are needed to develop a sizeable and reliable supply of biomass feedstocks, and R&D is needed to maximise yields and minimise costs, focusing on the development and widespread deployment of second generation biofuels (including the use of lignocellulosic biomass) and integrated biorefinery plants. Speculative R&D on novel approaches, such as plant genetics, hydrogen production via biophotolysis, photofermentation and the like should be encouraged.*

The other technologies – hydrogen and fuel cells, synthetic fuel from more widely available fossil fuels (with carbon capture and storage), and electric vehicles – will no doubt continue to be developed in parallel. As Table I shows, there has been some progress, some of it significant. Their parallel development remains necessary partly because it is impossible to predict market conditions in the longer term, and partly because R&D outcomes themselves are unclear. R&D funding policies should remain open to all of these avenues.

Both hydrogen/fuel cell and electric vehicles would require costly distribution and refuelling infrastructures. For this reason, market introduction would almost certainly be in specific urban locations. Widespread use of either technology will be a long time coming, unless one of them becomes more competitive in the market. *R&D on hydrogen/fuel cells and/or electric vehicles should be matched by carefully phased building of the necessary infrastructures.*

Hydrocarbons will nonetheless play a major role in the transport sector for decades to come. For this reason, the urgency of demand reduction measures cannot be overstated.

Table I: Summary of transport options, and associated key issues

Time to widespread deployment	Technology	Key issues
Immediate/ Short term	Reduction in demand (smaller engine size; speed limits; transport mode switching)	No technological issues; is a matter of public policy and consumer behaviour change.
	Advanced high-efficiency ICEs	Ongoing R&D by the automotive industry has already produced major efficiency improvements; will continue; Europe is in the forefront of developments.
	Improved hybrid electric designs with petrol, diesel, biodiesel	Hybrid models already on the market; ongoing R&D by the automotive industry should produce refinements to all design aspects in the short term.
	Biodiesel; bio-ethanol as carriers	Technology already well established and new production capacity is under construction. Feedstock supply infrastructure needs urgent/significant development and support (limits to planting area are imposed by the needs of the food sector). R&D needed to support this; in particular, cost reductions, improved crops, and reduction of emissions involved in growing and harvesting/transport.
	Co-processing of biomass with fossil fuels	Development of hybrid processes used in existing refineries.
	Synthetic fuels from gas / coal Fischer-Tropsch	F-T process well established but capital-intensive; new processes beginning to be deployed but further R&D needed on process. Requires CCS for removal of CO_2 emissions.
	Biofuels from ligno-cellulosic feedstocks	Biorefineries processing ligno-cellulosic feed-stocks (e.g. from materials flows in the paper and pulp industries) could if successful give high-yield, low-cost biofuels; the chemistry, catalysts, etc, need extensive R&D.
	Electric vehicles (EVs) with advanced battery electricity storage	EVs are already on the market but with low range. Progress being made on battery designs to increase energy density. Would require dedicated electricity distribution network for charging. Would require major increase in electricity generation capacity. Lengthy recharging a problem. All-electric technologies do not play to automotive industry's current competitive strengths.
	Hydrogen with fuel cells	Demonstrator/concept vehicles already in operation with very high fuel efficiency but with on-board storage of H_2 at high pressure or cryogenic liquid. Requires large-scale production of H_2 from non-fossil sources or with CCS to avoid overall CO_2 emissions. Requires R&D on H_2 production and especially on compact storage. Distribution network required would be rather costly. PEM FCs require major cost reductions to compete with ICEs.
Long term	Air transport: hydrogen/ gas turbine	Major safety problems associated with on-board storage of liquid H_2. Otherwise, hydrogen/gas turbine technologies are well developed.

Conversion technologies for electricity and heat

Electricity and heat production together are responsible for the largest share of primary energy demand in Europe, and again are heavily dependent on imported oil and natural gas. It is essential to reduce this dependence substantially, although natural gas especially will continue to be used, providing conversion efficiencies much greater than with any other primary energy source. The main options are:

- Demand reduction through improvements in conversion efficiencies and end-use efficiencies; fuel cells may become an important new technology vector for efficient use of natural gas or hydrogen.
- Expansion of generation from renewable sources, especially wind, solar and biomass energy.
- Expansion of nuclear fission, bringing Generation III/III+ reactors on-stream, and after 2020 the introduction of Generation IV reactors; effective waste disposal/recycling.
- Efficient use of coal, with carbon capture and storage (CCS), most probably producing electricity or hydrogen.
- Nuclear fusion.

The options, and the key issues associated with each, are summarised in Table II.

In addition to conversion technologies, one of the critical tasks is the satisfactory integration of European grids for electricity, natural gas and eventually also hydrogen. This is necessary for smooth and consistent operation of the liberalised markets for electricity and gas, and for the dispatch of undispatched electricity (from large wind farms, for instance) and of distributed power generation. 'Smart grids' with electronically guided active interaction by customers are also necessary[2] .

Even with increased end-use efficiencies, demand for electricity is likely to continue to grow. Electricity use for hydrogen production would increase demand still further, as would any significant switch to electric vehicles. **Minimising demand through improvement of conversion and end-use efficiency is therefore essential**. None of the technology options listed above are adequate on their own to meet Europe's electricity needs, and nor should any one technology dominate the electricity/heat sector.

From the point of view of *greenhouse gas emissions over the full life cycle*, hydro and nuclear fission are the lowest emitters, followed respectively by wind, solar, biomass, and fossil fuels; of the fossil fuels, natural gas is the lowest, followed by oil, hard coal and lignite. Emissions from fossil fuels, including natural gas, greatly exceed all other options (in some cases by an order of magnitude).

From the point of view of *availability of primary fuel*, of course the renewable technologies draw on a finite but large and constantly replaced supply of energy, though biomass is more severely constrained by the availability of feedstock within Europe. Biomass for electricity and heat also potentially competes with biomass as a feedstock for liquid fuels. Gasification/combustion of biomass for electricity and heat may be the most efficient use of such feedstocks, particularly in a situation of constrained supply. Supply problems could possibly emerge with U^{235} in the second half of the century, though the latest NEA data on the uranium sources now thought to be available at current prices make that unlikely (ref. 4).

[2] *The SmartGrids Technology Platform is addressing all of these issues and mapping the extensive R&D needs.*

However, in current operating reactor designs, less than 1% of the energetic potential of natural uranium is used; fast reactors can in principle utilise the much more abundant[3] U^{238} and Th^{232}, and deployment of fast reactors could ensure fuel availability for hundreds and even thousands of years. Of the fossil fuels, there is sufficient coal to meet needs for centuries; global natural gas production is expected to peak within this century, and global oil production to peak in the short term.

The Community's policy is to utilise **renewables** to the extent that it is economically and technically feasible to do so. Renewables industry groups hope for public support in order to realise ambitious contributions – for example:

- The European Wind Energy Association has set targets for installed capacity in Europe (EU-15) of some 75 GW by 2010, and 180 GW by 2020 (ref. 5).

- Solar thermal systems could replace more than 30% of the EU's oil imports (ref. 6).

- The Photovoltaic Technology Research Advisory Council believes that the EU target for PV of 3 GWp installed in 2010 can be achieved, with a "ambitious though realistic" possibility of increasing this to around 200 GWp by 2030 (ref. 7).

In all of these technologies there are ongoing R&D needs (some of them extensive), with cost reduction, efficiency improvements and improved power prediction being important goals. The technical potential of ocean energy is great, but the extent to which this can be realised remains to be assessed. Together, renewables will not provide more than a fraction of Europe's electricity and heat needs. However, they can provide an important and increasing fraction. European industry has world-leading strengths in these fields, and should be supported. *Strong ongoing support is justified for R&D in wind energy, solar (low-/high-temperature thermal and PV), and biomass (as for liquid biofuels).*

Although there are acceptability problems in some Member States, the AGE is convinced that **nuclear fission** represents a good option from the point of view of operating cost, life cycle emissions, and availability of primary fuel, on the assumption that fast neutron reactors will be deployed in the mid to long term. The generation III reactors now available offer high levels of safety, low operating and decommissioning costs, and long operating lives. Their fuel utilisation will be two to four times greater than generation II reactors. Generation IV reactors are the longer term aim, however. It is necessary to develop reactors which utilise different and/or closed fuel cycles, and to reduce the quantity and half-life of waste products. In parallel, it is necessary to move forward the agenda on waste disposal and recycling (including innovative technologies still requiring major R&D investment, such as partitioning and transmutation in accelerators or reactors). *Strong support is needed to accelerate progress towards generation III+ and generation IV nuclear fission reactors. This entails a readiness to provide substantial funding support should the Generation IV Forum (GIF) evolve into an international collaboration. Such a collaboration might aim to accelerate the deployment of safe reactors at reasonable cost and with dramatically improved fuel efficiencies including minimisation of waste toxicity. Long term political commitment is of fundamental importance, if the necessary private investment is to be achieved.*

[3] *U^{238} and Th^{232} are not themselves fissile, but can absorb neutrons to form fissile nuclei.*

Nuclear fusion is a long term goal with the visionary promise of abundant, safe and relatively waste-free energy[4]. In the short to mid term, the ITER project will be the primary focus, together with other necessary investments such as the IFMIF. *In the longer term, a further ongoing commitment to fusion energy R&D will be necessary, in order to maintain Europe's competitive strengths in bringing fusion technology to the market.*

Some Member States have large reserves of coal, and most likely this will be used widely; coal imports from other regions are not regarded as likely to adversely affect security of supply. **'Clean coal' technology** is thus clearly urgently needed also. The capital costs of advanced coal plant are higher than those of gas-fired plant, but increasing oil and gas prices render 'clean coal' power generation more competitive. *Considerable R&D is still needed, including materials research, integration of CCS techniques, and research to allow 'clean coal' plants to operate at cyclic loads and not only base load.*

Environmentally acceptable use of fossil fuels depends on the ability to capture and permanently store a high fraction of the CO_2 emitted. In particular, since coal reserves are so high and since coal can be used for power generation, production of liquid fuels, and as a basis for the many components currently manufactured from heavy oil fractions, carbon capture and storage (CCS) could be a vital technology. There are environmental concerns, and hence issues of public acceptability. There are also outstanding issues in international law, including the issue of long term responsibility, and these need to be addressed. *R&D is still needed to test the viability and long term safety of CCS in different situations. The primary R&D issue, however, is integration of coal generation with CCS, and the industrial maturity of CCS.*

R&D in other areas is ongoing – such as deep geothermal (greater than 3 km) and ocean energy (wave, marine current). The real potential of each of these remains to be tested. Fuel cells (SOFC including IT-SOFC[5], MCFC[6]) providing heat and electricity may become important for smaller, localised applications, along with biomass fired CHP plant.

[4] *The nuclear waste resulting from neutron-activated components have half-lives 10 to 100 times shorter than the fission products of a conventional nuclear power plant*
[5] *Intermediate Temperature (500° C - 600° C) Solid Oxide Fuel Cells*
[6] *Molten Carbonate Fuel Cell*

Table II: Summary of electricity/heat conversion technology options, and associated key issues

Time to widespread deployment	Technology	Key issues
Short/ immediate term	Low/medium temperature solar thermal applications for hot water, heating, cooling, industrial processes, etc	Already widely deployed (worldwide installed capacity in 2003: 109 GWth). R&D needs include materials R&D, including advanced insulation and energy storage materials. R&D needed on solar cooling, to provide higher performance and lower costs, and for application in the industrial sector. Public policies to stimulate the market are needed.
	Combined Cycle Gas Turbine (CCGT)	Well known and widely deployed. High efficiency, low relative emissions, low cost, flexibility in operation makes it an attractive choice for utilities in the short term.
	Nuclear fission (Gen III/III+)	Advanced designs already available and under construction. Low fuel utilisation, waste disposal/recycling and public acceptability problems remain. Major R&D investment needed on waste disposal and recycling, including innovative approaches such as partitioning and transmutation in accelerator driven systems or in reactors.
	Wind energy (including offshore/deep offshore	Needs better predictability of wind/power output. Next-generation wind turbines require advanced materials/improved controls. Costs of construction (including undersea electricity transport) and operation for deep offshore represent a barrier. System and grid issues very important as wind capacity grows (see below).
	System integration [not a conversion technology but grid issues represent a major barrier to development of the European electricity system]	Short term: R&D in progress on grid issues focusing on reliability, economic, environmental, and legal/regulatory aspects of operation of the liberalised markets for electricity (and gas). Short to mid term: R&D needs on the interaction of the grids for electricity and gas; integration of large amounts of undispatched but rather centralised electricity generation sources (e.g. large wind farms); integration of distributed electricity generation sources. Mid to long term: R&D needs include development of 'smart grids'; and the interaction of the grids for natural gas and hydrogen. Progress is being made, but grid issues will remain central to the development of the future European electricity, natural gas and hydrogen systems).
	Solid biomass	May represent the most efficient use of biomass for energy. Technology already available for co-combustion of coal with biomass, but R&D needed for cost reduction and development of gasification technologies. Well suited for distributed generation with use as combined heat and power. R&D also needed in areas such as gasification of black liquor, and burning of corrosive crops.
	Fuel cells (SOFC, MCFC)	R&D needed for cost reduction and on materials; suited for smaller, distributed applications IT-SOFC holds promise but R&D needed (e.g. to improve ion transport and hence also efficiency].

Table II: Summary of electricity/heat conversion technology options, and associated key issues

Time to widespread deployment	Technology	Key issues
	Geothermal energy (including deep geothermal – HDR/HFR)	Technologies for low-depth geothermal well established, but suitable sites are limited, though low-depth geothermal/heat pumps have no such limitation. Deep geothermal (>3km) holds promise but very high costs and further R&D needed.
	Carbon capture and storage (CCS)	A critical technology for continued use of fossil fuels for electricity but also for other uses (e.g. synthetic fuels), especially coal, though CCS will involve important losses in efficiency. Many projects currently under way but many R&D issues remain, including improved/new separation/capture processes, and testing viability and safety of different CO_2 storage options, along with legal and public acceptability issues.
	Cleaner use of coal (steam/ gas turbine, combined cycle) with CCS	Well established already, but R&D needed for higher efficiencies (higher operating temperatures, new materials).
	Advanced fossil fuel plants (super/ultra-supercritical steam Integrated Gasification Combined Cycle (IGCC), with CCS	Technologies available and being deployed but an ongoing programme of R&D is needed to develop new materials and integration of clean coal power generation with CCS. Requires carbon capture and storage if coal use is to be an option in the mid to long term.
	Solar photovoltaic (PV)	Already available but breakthrough R&D needed if low-cost mass production of PV is to be achieved. Off-grid applications are already cost-competitive; if costs can be reduced, the potential is high also for grid-connected electricity. Further R&D on integration of PV with building design/construction. R&D needs for PV exist in basic and applied research, demonstration, and in socio-economics, standardisation, QA and environmental issues.
	Solar thermal power plants	Systems in operation or starting construction but major cost reductions still needed, together with materials research. Considerable potential in southern Europe.
	Ocean energy (wave, sea current)	Many competing small-scale designs available now, with some about to be deployed with grid connection. Remains to be established whether current technologies will be able to make a sizeable contribution, though potential is very high.
	Nuclear fission – Generation IV	Generation IV Forum assessing six designs, including high-temperature and fast breeder designs. Fast breeder fission could improve fuel utilisation by an order of magnitude. New materials are needed. Many substantial R&D needs mean market introduction of G.IV reactors will not appear before 2030.
Long term	Nuclear fusion	ITER project will remain the focus for R&D for some decades. Acceptable power ratio, continuous operation and high costs mean fusion will not be deployed till post-2050.

End-use efficiency

For most Member States, there has been a steady improvement in energy intensity of between 1% and 1.7% per year over the long run, due mainly to a combination of absorbed efficiency in all sectors and structural change in industry to less energy intensive sectors and technologies. The long run overall efficiency improvement arises also partly from improvements in conversion efficiencies. The concern of this section is exclusively with *end-use* efficiency: the efficiency with which an energy carrier is converted into useful work for the last user in the energy chain: in transport, in the home, in offices, in schools, in agriculture and in industry. To some extent, this is not a primary concern for programmes offering funding at a European level, since the necessary R&D to achieve energy efficient products for *end-use* is generally carried out by industry as part of its ongoing efforts to remain competitive. The real problem has been the slow uptake of better technologies, and this is likely to remain unless energy prices remain high and/or unless the full external costs of energy to consumers are built into prices. An affluent society may only serve to increase the level of market failure, unless there are other interventions. But there is an extensive range of energy efficient products on the market for all sectors – so extensive that it is not possible to produce a concise summary of technologies as was done for transport and electricity/heat production – and the real need is to see a much higher penetration of such technologies. We know that this can be achieved: major improvements in energy efficiency were achieved during the earlier energy crises of the 1970s and 1980s, partly due to changed choices by consumers, and partly to vigorous but temporary policy decisions to favour energy efficient *end-use*. *From a technical point of view, the recently proposed Commission objective of a 20% overall improvement in energy efficiency in Europe by 2020 (ref. 8) could be easily achievable. A longer run target of (say) a 50% improvement in European energy* end-use *efficiency by mid-century should be agreed.*

The potential for energy efficiency improvements in all sectors is great.

- In the **transport** sector, the introduction of advanced diesel engines has reduced fuel consumption by about 20% to 30% per vehicle. The next generation of hybrid electric drive trains will permit a 30% decrease in fuel consumption, particularly for urban journeys. Beyond this, the next step could be hydrogen/fuel cell technology.

- In the **built environment**, with new materials and new building design concepts, incorporation of a range of renewable technologies (biomass, solar thermal and PV, heat pumps, etc[6]), and many other renewable or efficient technologies, reductions of between 60% and almost 100% are already achievable with new build, and there is enormous potential for improvements in existing buildings.

- Even though the **industrial sector** has been generally more dynamic than others in taking decisions in favour of energy-efficient options, the increased costs of energy to European industry arising from the long-run operation of the European Emissions Trading Scheme (EU-ETS) means that a special effort is needed to introduce radically more efficient technologies where possible, though recent events have shown that setting realistic but challenging limits within the EU-ETS may not be easy. Innovative technologies have the potential to improve efficiencies of some important processes by 40% to 60% (ref. 9). There is a need to stimulate real innovation in energy-intensive industrial processes, in addition to the incremental improvements more usually sought by enterprises.

[6] *Strictly speaking, these are not energy efficiency actions per se; however, they may often be easily included in the design of a low-energy building and are included here for completeness.*

EU publicly funded energy R&D priorities

Previous assessments (ref. 11) have concluded that EU energy research funding must cross a wide range of technologies and options. Our assessments (ref. 7, 10) confirm that this remains the case, and many of those technologies need large-scale, costly R&D if they are to be brought to commercial deployment in the timescale needed. But if limited funding is spread too thinly, it will be inadequate to stimulate or influence energy R&D in any given area. It is therefore desirable to prioritise, and the previous sections suggest the following priorities.

For the **transport sector**, those technologies that contribute most, and most immediately, to the Community's long term objective of a sustainable energy system[7] include:

- **Reduction in demand** via common European policies *(research needs in behaviour change and socio-economic issues; traffic management systems)*.
- **Advanced high-efficiency ICEs** for use with hydrocarbons and bio/synthetic fuels; and improved hybrid designs *(ongoing R&D by the automotive industry)*.
- **Development of a biomass feedstock infrastructure** for biofuel production with maximum yields, including biofuel production from ligno-cellulosic feedstock *(warranting European funding and strongly coordinated/planned public policies)*. However, the two options of hydrogen/fuel cells and electric vehicles (at least initially for short range applications) could be viable longer term technologies, and *these should be pursued also.* It is difficult to see how the use of synthetic fuels from fossil sources can be avoided, unless there were a drastic reduction in road transport use.

With regard to electricity and heat conversion technologies, those that offer the most potential in terms of providing a path towards an energy system that is more sustainable (from the points of view of emissions management, security of supply, and commercial competitiveness) in the long run include:

- **Renewables technologies** known to provide a major contribution in both the short and longer terms, including wind energy (on, off, and deep off-shore), solar PV, solar thermal (low/medium/high tem perature), and biomass *(EU-level public funding will add value in all of these areas)*.
- **Nuclear fission:** deployment of generation III reactors, accelerated development of generation IV reactors with different or closed fuel cycles, and waste disposal/recycling *(substantial EU-level R&D support is needed, along with open public debate on issues of public concern)*.
- **Nuclear fusion** *(necessitating a continuation of Europe's long term commitment to international fusion R&D activities)*.

Given that the use of **coal** will increase in Europe and globally, conversion efficiency improvements along with **CCS** are of importance both for the European energy system and to maintain the competitive strengths of European industry. **Grid issues** are of central importance in developing an integrated European system, and *must be supported*.

[7] *Though no technology can be said to be fully sustainable, since trade-offs are always involved.*

Other renewables areas (e.g. deep geothermal, ocean energy) may contribute in the future, and *European funding support would help to advance and test these.*

***End-use* efficiency** will generally speaking be pursued by industry without any support. However, in addition to *strong public policy interventions to increase citizens' commitment to reducing energy use and energy-related emissions, EU-level funding support is warranted for innovative approaches with high potential for energy/emissions reductions across Europe, in all sectors including industry.*

Crosscutting R&D is crucially important in almost all energy fields; key areas include materials research (for operation in demanding environments), biotechnology, socio-economic and behavioural research. *It is essential to provide ready access for energy-related crosscutting basic and applied R&D within the other FP7 thematic programmes.*

Energy infrastructure development is needed for biofuels (development of a complete/viable indigenous supply chain), nuclear fission (e.g. material test reactors), hydrogen/fuel cells (phased development of production, distribution and storage infrastructure); nuclear fusion IFMIF (International Fusion Materials Irradiation Facility), offshore wind energy (improved wind speed and power prediction), solar thermal (test facilities). *Strong EU support is needed.*

Research infrastructure development: *The European Strategic Forum for Research Infrastructure should be urged to include energy technology as a high priority. A high quality database of European energy research groups should be established and maintained. Overall strategic direction of European energy R&D would be facilitated by a dedicated policy analysis/modelling unit located in the EC Energy Directorate.*

Breakthroughs in energy technology may well be achieved from fields of research outside the mainstream of energy R&D, for example, utilising and adapting processes found in nature, such as photosynthesis. *European support is justified for novel and innovative research with potential for new technologies that might in the future provide cheap, clean, abundant energy.*

In summary, ***the primary strategic focus for EU-funded energy R&D****, then, should be on:*

- *Those technologies that can make a significant difference to consumption of fossil fuels in the immediate and short terms (e.g. renewables, innovative approaches with potential for significant energy efficiency improvements in widely used applications).*
- *Grid issues to allow for efficient operation of integrated distribution systems incorporating the demands of multiple small- and large-scale electricity and heat generation by diverse technologies.*
- *Longer term research likely to lead eventually to technologies that are sustainable from economic, social and environmental viewpoints over the long run (e.g. nuclear fission with generation IV and effective waste disposal/recycling technologies; nuclear fusion).*
- *Crosscutting R&D of central importance (e.g. materials, biotechnology, nanotechnology).*
- *Supporting the energy R&D infrastructures that are needed for progress.*
- *Novel and innovative R&D with high risk but also with high potential.*

Enabling measures

European funding plays a minor role in the overall expenditure for energy research, but it is none theless of great importance in shaping European energy research priorities and in bringing together European researchers. It is the AGE's strongly held view that the budget proposed for energy in FP7 is inadequate: arguably, there is no other area of research of greater importance or urgency for the well-being of society in Europe and the world. The FP7 period of 2007-2013 is one in which substantial progress *must* be made. *Ways must be found to increase European-level funding for energy R&D within the FP7 period, including additional pooling of funds by Member States for specific shared research actions. Variable geometry approaches are highly desirable, including combinations of private and public financial institutions.*

Many of the strategic problems we face in European energy research are shared with other regions and countries in the world. In any case, some are of a nature or scale such that they cannot effectively be tackled by Europe alone, but necessitate an international approach. *Europe must take a leading role in developing international approaches to energy R&D. Joint Technology Initiatives are of immense importance: the European funding available for participation in large scale initiatives must be adequate to give the EU a powerful voice in steering and implementing these initiatives. Europe must also devote much greater attention to cooperation on energy technologies with the developing and transition economies of the world, with a preparedness to back this with adequate finance.*

The organisation and management of European energy R&D urgently needs development in order to increase effectiveness (ref. 12). It is essential that there be the closest collaboration between industry and the organisations providing public funding. Today, when there are so many uncertainties about the future, when so much of the necessary R&D is long term and risky, when the future mix of energy technologies is so strongly affected by public policy decisions, the need for collaboration has never been stronger. *There is a need to strengthen and accelerate the approaches to coordination and planning started in FP6. The role of Technology Platforms in key strategic areas must be strengthened by the development of consensual Strategic Research Agendas.*

A growth of recognised centres of excellence (centralised or distributed) would allow European energy R&D to develop more effectively, and would reflect the situation as it is today in other countries including the US, Japan and some developing countries also. *There is a need for far greater attention to the development of shared research facilities and centres of excellence in areas of energy R&D where this would lead to greater effectiveness.*

Key conclusions and recommendations

There are important *specific* recommendations throughout the various sections of this report. This final section is intended to highlight what the AGE believes to be **key general recommendations for decision makers.**

- Europe faces the possibility of steadily worsening oil and gas supplies in the very short term, arising from bottlenecks in global oil production and more seriously from the peaking of world oil and gas production[8]. Enhanced recovery and exploitation of so-called 'non-conventional oil' may prolong the plateau period, but it will not prevent the peak from occurring. *Europe must prepare urgently for more expensive oil (and later gas) supplies.*

- Climate change presents very substantial threats. Europe's response, including a shift towards a climate-neutral energy supply system must be coordinated globally lest economic problems cause social resistance, thus delaying or jeopardising the transition. *Energy policy must be formulated in the light of global consensus about necessary actions against global warming.*

- Some technologies, especially those that would permit a significant reduction in energy demand, are already available. *Opportunities for energy demand reduction through changed consumer behaviour and improved efficiencies should be strongly supported by a shared European policy approach, as a matter of urgency.*

- Most of the necessary energy technologies need further development to make them more cost-effective or are not yet available. And **the AGE believes strongly that the funding proposed for FP7/Euratom is insufficient.** *Progress must be made on the development of multi-lateral funding for major projects of common interest, with funding from the regions, Member States, Europe and the private sector. Close collaboration with industry is essential. And in some areas Europe must be resourced to allow it to play a leading role in international collaboration and cooperation.*

- European energy R&D remains over-fragmented, and effectiveness suffers as a result. *Rapid progress must be made in pursuit of the objectives outlined by the Lisbon Council, and should include improved coordination of regional, Member State and European programmes and policies, the development of centres of excellence and of the necessary energy research infrastructures.*

- The AGE believes that the European Commission's Directorate General for Research is pursuing appropriate and important objectives, *and deserves more support from the Member States and from European society.*

- The AGE welcomes the recent proposals for a common approach to European energy policy, notes the Commission's call (ref. 1) for an appropriately resourced strategic energy technology plan, and hopes that this report will represent an input to such a plan. AGE also welcomes the proposal for a regular strategic EU energy review to be presented to the Council and Parliament. *These should be progressed on an urgent basis.*

Above all, there is a need to accept the urgency and importance of action now. Our problems today result from a lack of commitment to energy R&D in the past. We cannot now afford to repeat this mistake. There is no time to spare.

[8] *Assuming a continuing rapid growth in world economies, and a modest rate of discovery of new oil reserves, there is a growing view that global oil production may reach a maximum as early as the next decade. Lower-growth scenarios and assumptions of larger than expected discoveries of new reserves push the date for likely maximum oil production to 2020-2030. Natural gas maximum production is likely to follow the same trajectory, two to three decades later.*

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Europe has set a long term objective to change to a sustainable energy system for Europe. The report examines the key drivers of change, and concludes that the task is both important and urgent. Furthermore, the needed energy technologies are not yet ready, and require extensive further R&D. Two critically important fields are energy for transport and conversion technologies for electricity and heat; the report presents the options and identifies key issues in relation to each. End-use efficiency is identified as a further important area, with some R&D needs at a European level, and a need for an ambitious long term target. Broader energy policy frameworks must support and encourage energy R&D. Funding and commitment remain inadequate, and new organisational and funding structures must be found in the early days of FP7. A sense of immediate urgency is vital.

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