The Role of Electricity

A New Path to Secure, Competitive Energy in a Carbon-Constrained World
Union of the Electricity Industry – EURELECTRIC seeks to contribute to the competitiveness of our industry, to provide effective representation for the industry in public affairs, and to promote the role of electricity in the advancement of society.

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In addition to this brochure, a more detailed report is also available online at www.eurelectric.org; please apply above to be sent a printed copy. Interested readers are also advised to consult the website to obtain the extensive technical reports from the project partners, the presentations from the fact-finding workshops that have been held during this project and other detailed information.

EURELECTRIC pursues in all its activities the application of the following sustainable development values:

**Economic Development**
Growth, added-value, efficiency

**Environmental Leadership**
Commitment, innovation, pro-activeness

**Social Responsibility**
Transparency, ethics, accountability

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MARCH 2007
THE ROLE OF ELECTRICITY

A NEW PATH TO SECURE, COMPETITIVE ENERGY IN A CARBON-CONSTRAINED WORLD
“The EURELECTRIC Role of Electricity study will make a valuable input to the energy policy debate.”

Andris Piebalgs  
EU Energy Commissioner
FOREWORD

There is now overwhelming evidence that emissions of greenhouse gases will have to be reduced very substantially during the coming decades. This means that climate change is today and will remain for the foreseeable future an important item on the political agenda and an important element of our business agenda. Managing the security of Europe’s energy supplies is also increasingly becoming a major issue. Solutions must be found which help to maintain the competitive strength of Europe’s economy.

EURELECTRIC has for many years brought pro-active input to this debate. Our preparatory analysis and simulations of *Greenhouse Gas Emissions Trading* and our *Energy Wisdom Programme*, among other initiatives, bear witness to our engagement in this field.

Continuing this valuable tradition, I am proud to share with you EURELECTRIC’s vision of a cost-effective pathway to an energy-efficient, low-carbon and energy-secure European energy system.

It is profoundly encouraging that many elements of this pathway are in line with the recent proposals from the European Commission for an *Energy Policy for Europe*. However, the pathway takes the logic and consequences of the Commission’s proposal further. Energy-efficiency improvements must be exploited to the full. The move to a low-carbon electricity system must be accelerated by pro-actively using and developing all low-carbon technologies. And, last but not least, it is essential to develop the remarkable potential offered by combining low-carbon electricity with efficient electro-technologies. These hold the promise of making both the heating & cooling and road transport sectors much more energy-efficient, drastically less carbon-emitting and far less dependent on imported hydrocarbons.

This pathway is not “pie in the sky” speculation. It relies on a balanced mix composed of entirely feasible elements.

All these elements must be put to work if we are to see the desired results. If not, we will fail. The European electricity industry is committed to this agenda. But it must be shared by policymakers and stakeholders and be translated into strong, coherent and urgent action. Starting from now.

Rafael Miranda
President
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Executive Summary

Future energy policy will be driven by the triple challenge of making substantial reductions in emissions of greenhouse gases while ensuring a secure supply of energy, all at reasonable cost to the economy.

Towards the end of 2005, EURELECTRIC launched a project entitled The Role of Electricity, whose purpose was to draw up an authoritative view on what role electricity will play in helping to meet these challenges.

The project was carried out in cooperation with several external partners. An academic consortium led by Leuven University explored the likely evolution on the demand side, VGB Powertech looked at the supply side, and their findings were integrated into a modelling database and scenario work under the responsibility of a team at the National Technical University of Athens led by Professor Pantelis Capros. General assistance and work on road transport were provided by McKinsey & Company.

The project investigated the impact of different demand-side and supply-side policies and technologies through quantitative modelling and scenario building up to the year 2050. The PRIMES energy system model was used for detailed projections up to 2030 and the PROMETHEUS model for broader projections up to 2050. Working against a baseline scenario, several alternative scenarios were set up to explore the impact of a theoretical mandatory reduction in greenhouse gas within the EU25 of 30% by 2030 and 50% by 2050, versus the 1990 level.

Four scenarios were investigated:
- The Baseline scenario, which includes ongoing current policies on energy efficiency and support for renewable energy sources (RES), but does not expand them, nor does it foresee any change in the current constraints on the development of nuclear energy or envisage the emergence of carbon capture and storage (CCS) technology
- An Efficiency & RES scenario, which centres on energy efficiency and renewables, with the same constraints for nuclear energy as under Baseline, and without the emergence of CCS
- A Supply scenario based on a nuclear renaissance and CCS technology
- A Role of Electricity scenario, which envisions the use of all options towards a low-carbon energy system - energy efficiency, renewables, nuclear energy and CCS. The scenario exploits the synergy between a low-carbon electricity supply system and efficient electro-technologies, including in areas traditionally largely limited to direct combustion of oil and gas – namely road transport (through the introduction of plug-in hybrid cars) and heating & cooling (through heat pumps)

The project results first highlight that the Baseline scenario is unsustainable, both in terms of greenhouse gas emissions and gas and oil import dependency.

All alternative scenarios deliver the required reductions in CO₂-emissions. They were benchmarked against parameters such as total energy cost, oil-gas dependency and carbon value. The Role of Electricity scenario performs better due to its more balanced and synergy-seeking approach. This scenario:
- convincingly performs best in terms of controlling both total energy costs and oil and gas import dependency. The objective of carbon reduction is reached without additional total energy costs compared to Baseline. Oil and gas import dependency in 2030 and 2050 remains almost stable compared to 2005 whereas all other scenarios see significant rise in oil & gas dependency.
- is the only scenario leading to a reasonable and stable level of carbon value - some €40-50/tonne CO₂ - whereas the other scenarios peak at €120/tonne CO₂. This has great significance not only in economic terms but also in terms of worldwide relevance and of acceptance of EU climate change policies.
• is the most robust scenario. Due to its inclusive portfolio approach it is less vulnerable to unforeseen events and can better exploit opportunities offered by technological development. The portfolio approach is based on reasonable development of all options, avoiding extreme choices that could jeopardise the implementation of the other scenarios. A sensitivity analysis with substantially higher fuel costs confirms the robustness of its conclusions.

• provides the best prospects for economic development in a carbon-constrained environment. All scenario calculations assume economic growth of 2% per year but there are clear indications of better prospects for economic development - lower overall energy costs; reduced import dependence; lower and more stable carbon-abatement cost; introduction of a whole range of future-oriented technologies with worldwide potential; a portfolio approach with its intrinsically greater robustness - under Role of Electricity.

• enables massive synergy between a low-carbon electricity supply and energy-efficient electro-technologies, which constitutes an essential part of the solution. This synergy is important in all sectors of the economy but is particularly significant for two sectors that have until now been highly dependent on the direct combustion of oil and gas - namely spatial heating and road transport. For instance by 2030, a heat pump driven by the electricity supply mix of the Role of Electricity scenario is shown heating a house or office at a small fraction (around 80% reduction) of the CO₂ emissions made by current oil or gas heating, simultaneously reducing oil/gas consumption by 90%. On the same time-horizon, driving a plug-in hybrid car in electrical mode, with the Role of Electricity supply mix, entails a spectacular (circa 70%) reduction in CO₂ emissions, while reducing oil/gas consumption by some 80%. The scenario assumes a reasonable - not wildly ambitious - penetration of these technologies. Their impact will continue to expand beyond the time horizon of the study and could also be accelerated if supportive policies are enacted.

Thus the Role of Electricity project brings us to a positive, future-oriented conclusion:

Only a European energy policy based strongly on demand-side energy efficiency, active development of all low-carbon supply sources and active exploitation of the synergy between low-carbon electricity supply and efficient electro-technologies - especially in the heating & cooling and transport sectors - will ensure the transition to a low-carbon economy while contributing to both the security of Europe's energy supply and the competitiveness of the economy.
Policy Recommendations

A positive message:
The analysis described in this report shows that electricity has the potential to contribute substantially to the three main pillars of European energy policy. It holds the key to substantial reductions in greenhouse gas emissions at reasonable cost to the economy, while at the same time helping to reduce oil and gas dependency.

In order to seize this opportunity, a clear energy policy pathway must be implemented without delay. This new path energy policy for the coming decades must be based on five equally important keystones, which must be pro-actively developed in parallel.

- Unleash the potential of energy efficiency
  An energy savings culture must be encouraged among all elements of society, using a variety of tools. Education, incentives, standards and labelling, research and technological development – each one must contribute to fostering energy-efficiency in all sectors of the economy: in households, in industry and service sectors, in transport and through all energy vectors and technologies.

- Develop a low-carbon electricity system by using all available options
  The next decades must see further progress towards a low-CO2 electricity generation mix through the pro-active use and development of all available options: hydropower, other renewable energy sources, nuclear energy, and clean fossil-fuel technology including carbon capture and storage. Any policy that tends to exclude specific elements of this balanced portfolio will fail to build a robust and economically-sound low-carbon electricity system.

- Intelligent electrification of the economy
  Intelligent electrification of the economy entails two vital imperatives. The first is to improve electricity efficiency on both the supply and demand side by developing more efficient power generation technologies and by improving efficiency in all kinds of applications including lighting, standby power, motor drives, etc. The second is to actively develop the far-reaching synergy between CO2-low electricity supply and energy-efficient demand-side electro-technologies. This process must be accelerated in many industrial or commercial applications and public transport and must be pro-actively extended to two sectors where electrification allows very substantial progress in terms of energy-efficiency, CO2-emissions reduction, and oil/gas dependency: heating and cooling through the use of heat pumps; and road transport via plug-in hybrid cars.

- Consistent deployment and a market-oriented approach
  The benefits of both existing and new technologies, on both the demand and supply side, must be exploited through practical take-up. This calls for a consistent deployment strategy oriented both to making widespread use of existing technologies, and to making new technologies a business reality through R&D, demonstration programmes, long-term CO2 price signals and removing barriers to market integration. Public support policies, where these prove to be necessary, should be organised in such a way as to promote cost-efficiency and to foster speedy integration of new technologies into the market. The long-term nature of supply-side and of certain demand-side energy investments requires long-term visibility for carbon pricing so as to facilitate the integration of climate change action into investments and business strategies.

- Global cooperation on global issues
  The new path energy policy reinforces supply security and fosters a worldwide approach to climate change through diversification of energy supplies, international solidarity mechanisms, partnerships between suppliers and users of energy at international level and in the business domain, international cooperation on R&D and demonstration projects, and an international framework for climate change policies and cooperation.
**PROJECT AUTHORS**

The project was undertaken in three work blocks: a) future development of energy demand and electrotechnologies, b) future development of electricity supply technologies and c) energy modelling. EURELECTRIC worked in close cooperation with a number of partners whose expertise and close involvement made the project possible, each partner focussing on a specific domain:

- **Demand side aspects**: a consortium led by Professor R. Belmans and Professor K. Van Reusel of the University of Leuven, together with the University of Coimbra, the University of Toulouse, LABORELEC and the University of Bayreuth
- **Supply side aspects**: VGB PowerTech led by Dr. F. Bauer
- **Modelling**: E3MLab at the National Technical University of Athens, led by Professor P. Capros with L. Mantzos, N. Kouvaritakis, V. Panos, and V. Papandreou; and J-F Guilmot (ESAP)

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INTRODUCTION

There is growing consensus worldwide that energy policies serving the current and future generations of citizens will need to respond to the triple challenge of drastically curbing greenhouse gas emissions, while continuing to ensure a secure energy supply, through solutions that are both economically feasible and provide prospects for economic growth and prosperity on a global scale, in particular for developing countries.

The quotes below give some indication of that consensus and what it really means for our planet.

“Energy is essential for Europe to function. But the days of cheap energy for Europe seem to be over. The challenges of climate change, increasing import dependency and higher prices are faced by all EU members.”

(“An Energy Policy for Europe” - Communication from the European Commission, 10 January 2007)

“Global energy demands are expected to grow by 60% over the next 25 years. This has the potential to cause a significant increase in greenhouse gas emissions associated with climate change.”

“Secure, reliable and affordable energy sources are fundamental to economic stability and development. Rising energy demand poses a challenge to energy security given increased reliance on global energy markets.”

(Climate Change, Clean Energy and Sustainable Development, G8 Gleneagles – July 2005)

“The world is facing twin energy-related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by consuming too much of it.”

“The ability and willingness of major oil and gas producers to step up investment in order to meet rising global demand are particularly uncertain.”

(World Energy Outlook 2006 - International Energy Agency)

“The future energy policy has to focus on the three aspects of sustainability. (...) In terms of concrete action, this translates into energy policy being driven by a threefold objective: competitiveness, environment (within which combating climate change is a priority), and security of supply. Any energy-related measure or proposal has to be benchmarked against this threefold objective to ensure coherence.”

(Second Report of the EU High Level Group on Competitiveness, Energy and the Environment, 30 October 2006)

“There is still time to avoid the worst impacts of climate change, if we take strong action now.”

“The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response.”

“The investment that takes place in the next 10-20 years will have a profound effect on the climate in the second half of this century and in the next. Our actions now and over the coming decades could create risks of major disruption to economic and social activity, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century. And it will be difficult or impossible to reverse these changes.”

(Stern Review: The Economics of Climate Change, October 2006)
The electricity industry is ready to take up its role.

The electricity industry, in particular in the industrialised world, must play an important, pro-active role in providing economically feasible solutions for ensuring security of supply and achieving reductions in greenhouse gas emissions, as highlighted in a joint declaration issued by the industry’s US, Canadian, European, Japanese and Australian associations:

“... the five associations reaffirmed that global climate change poses a risk to the global environment and that a key transitional element in mitigating this risk is reducing the energy and GHG emissions intensity of national economies. They noted that secure, reliable and affordable energy sources are fundamental to economic stability and development goals.”

(Declaration from the High Level International Electricity Industry Summit, 2-4 October 2005)

“The coming decades will be dominated by the challenge of developing an energy-efficient, low-carbon, energy-secure and competitive economy. We believe these expectations can and should be met by further electrification of both the European and global economy, as electricity provides a unique, economically-competitive solution which can help to drastically reduce oil dependency, cut down on CO₂ emissions and boost energy efficiency.”

(EURELECTRIC Vienna Declaration, 13 June 2005)

The European electricity industry, through its representative body, EURELECTRIC, launched a project in September 2005 on the Role of Electricity. The project covers the time horizon to 2050, which is consistent with the long lifetimes of many energy-related investments and thus relevant for both policy-making and industry decisions being taken today. Its purpose is to draw up an authoritative view on the future role of electricity in relation to the triple challenge of climate change, security of supply - in particular regarding oil and gas dependency - and economic competitiveness.

Key questions are:

• What existing or new energy-efficient demand-side technologies can play a key role during the coming decades and what will be their impact?
• What existing or new low-carbon energy and electricity supply technologies can play a key role during the next decades and what will be their impact?
• What are the benefits of a balanced energy policy, based on actively developing and deploying all low-carbon demand and supply options - energy efficiency, renewables, clean fossil fuel with carbon capture and storage, and nuclear energy?
• What are the synergies between, on the one hand, the transition to a low-carbon electricity supply and, on the other hand, the expansion of efficient electro-technologies on the demand side, in particular in the transport and heating & cooling sectors?
• What conclusions can be drawn with regard to the future role of electricity?
• What policy recommendations emerge from this analysis?

The project covers the 2006 European Union of 25 Member States. Obviously, the project has a much wider relevance and is also meant to contribute to the worldwide debate on reorientation of energy policies.
Demand: Focus on Energy Efficiency
Demand: Focus on Energy Efficiency

The project partners investigated the prospects for demand-side developments and examined the impact of existing and new technologies in different areas of the European economy. They sought to provide quantitative analysis as far as possible to 2030, with a more qualitative analysis from 2030 to 2050. The different sectors, and the most important technologies and applications within those sectors, were thoroughly investigated. A potential for significant energy-efficiency improvements was identified in nearly all cases. These findings provided input to complement the PRIMES economic model used for scenario analysis.

An overview of energy demand and electricity demand in the EU-25 is given in the table below. The prospective figures for 2030 are taken from the PRIMES-model baseline calculations. Baseline calculations represent the natural evolution of demand while continuing present energy policies.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Energy Use (MTOE)</th>
<th>Electricity Use (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2030</td>
</tr>
<tr>
<td>Industry</td>
<td>339</td>
<td>393</td>
</tr>
<tr>
<td>Residential</td>
<td>295</td>
<td>352</td>
</tr>
<tr>
<td>Tertiary (service sectors)</td>
<td>174</td>
<td>227</td>
</tr>
<tr>
<td>Transport</td>
<td>361</td>
<td>402</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1168</td>
<td>1374</td>
</tr>
</tbody>
</table>

By 2030, under baseline conditions, transport would remain the largest energy consumer, while growth would be largest in the tertiary sector (+1% per year). Industry would still be the major user of electricity, while growth in electricity demand would be mainly in the residential and tertiary sectors (+1.9% per year).

Energy efficiency improvements will be an important goal in all energy applications but they will be paramount in the transport sector, which is not only the major user of energy, but also relies overwhelmingly on imported oil as its energy source. To a significant extent, the same consideration holds for space heating, relying on imported gas and oil. In the residential and tertiary sectors, many specific electricity applications can be targeted for efficiency improvement.

A bottom-up approach was adopted for the **Demand** section of the project. Major users were identified in every demand category together with their main potential for efficiency improvement:

- **Industry:** steel, non-ferrous, chemicals, glass, paper & pulp, engineering & automotive industry, timber, food & drink were scrutinised; a specific chapter deals with motor drives
- **Residential sector:** household appliances, plus heating & cooling, lighting and standby power for electronic devices
- **Tertiary sector:** lighting, heating & cooling and office equipment
- **Transport sector:** road transport and rail. Transport by air and water were not specifically considered
Six technologies or applications have been identified that promise to significantly improve the efficient use of energy, without detracting from the service provided:

1° efficient lighting in our homes, offices, factories and streets
2° heat pumps for residential and commercial heating and cooling
3° efficient DC power and standby power for home entertainment, communication and office equipment
4° efficient motor drive systems
5° suburban rail and high speed trains
6° the Plug-In Hybrid Electric Vehicle (PHEV) for private road transport

Of particular relevance are two electro-technologies that have the potential to greatly improve energy efficiency, reduce oil and gas dependency, and curb CO₂ emissions:

To cover the requirement for heating and cooling, ground-source heat pump technology taps into the environment. It relies heavily on renewable ambient energy and only uses electricity to upgrade outside external ambient energy to the inside needs of the building.

In the road transport sector, the Plug-In Hybrid Electric Vehicle (PHEV) complements the already efficient Hybrid Electric Vehicle by adding the possibility of charging batteries from the grid and offering full electric drive for urban travel.

Whereas the supply sector has a long-term outlook, hence the 2030-2050 horizon of this project, the demand sector is extremely varied. ICT applications will only have a lifetime of a few years, hence 2030 is a long time-horizon, while buildings have a 100-year lifetime and domestic appliances can easily reach a 25-year lifetime.

2.1 Efficient Lighting

Energy consumption via lighting systems is very significant and the lighting is a growing sector for energy demand. A growth of some 80% is to be expected by 2030 if current socio-economic patterns and policies remain unchanged.

There is a significant potential to save energy in lighting through research and development efforts and by the lighting industry continuously improving lighting systems.

Figure 1 illustrates the evolution in time of luminous efficiency, in lumen/watt, of common light sources, demonstrating the rapid advance in efficiency since the inception of electric lighting.

**FIGURE 1: COMPARISON OF LIGHTING TECHNOLOGY EFFICIENCY OVER TIME (LABORELEC)**
Basic characteristics of a lighting system

A lighting system is usually composed of a lamp, a ballast (for ignition and regulation) and a luminary (to distribute the light into space).

Lamps will convert electrical energy ("Watts" or "W") into useful light, measured in lumen ("lm"). There is a wide range of lamp efficiencies (5 to 200 lm/W) which are used for different applications depending on the "quality" of the light required and the price of the lamp.

Ballasts are necessary for certain lamp types. They should be as efficient as possible while limiting the harmonics sent back to the grid.

Luminaries will direct the light to the work-place in order to minimise loss of light to the surroundings. The right choice of luminaries is particularly important in office and industrial spaces.

Efficient lighting in our homes with CFLs and LEDs

A lamp in a domestic dwelling operates on average 1,000 hours per year.

Today two technologies cover the majority of residential use - incandescent lamps (GLs) and fluorescent lamps (FLs). Incandescent technology includes classic bulbs, halogens and low voltage dichromic lamps. FLs include both linear fluorescent lamps and compact fluorescent lamps (CFLs).

The oldest (since 1878) type of electric lamp is the incandescent lamp - the classic tungsten lamp. Its efficiency is low and it has an average life of 1,000 hours. Today, 85% of lamps sold for residential use are still standard incandescent lamps, and the most common lamp purchased consumes 60W.

In the search for more efficient light sources, new types of lamp have been developed with markedly higher efficiencies. Compact fluorescent lamps (CFLs) are the latest applications of mercury low-pressure discharge technology. They feature a narrow tube that is doubled back on itself and terminates in a plastic base. Compact fluorescent lamps with integrated electronic ballast and screw base are a direct replacement for incandescent lamps. They are typically 4-5 times more efficient than incandescent lamps, emitting up to 80 lumen/Watt, and have an average life of 12,000 hours. The most common choice of CFL is of 14W. An 11W CFL will reproduce the typical lumen output of a 60W lamp. However the consumer will be aware that the quality (more specifically, colour temperature) of the CFL is inferior to that of the incandescent lamp (though CFLs are improving in this respect) and will tend to compensate by specifying more light, so that we can observe a clear trend for the consumer to demand an increasing amount of light. This means that some improvements in lighting efficiency will be offset by the increase in the installed lumen output.

Sales of CFLs are growing faster than the overall increase in lighting appliances. Therefore it can be expected that efficient lamps will cover close to 50% of all lighting needs by 2030. Under this hypothesis, savings in kWh use for lighting can reach 30%, implying savings of 400 kWh per year in the average household. However, recent EU proposals to phase out incandescent lamps from as early as 2009 will clearly increase such savings significantly. There are also indications at the international level that incandescent lamps may be banned from the market. The Australian government has proposed to enact such a proposal from 2012. Such national policies are likely to accelerate the market penetration of CFLs and other efficient technologies in all markets as they encourage "network effects" and the development of economies of scale in manufacture, driving prices down.

The next revolution in lighting technology has already begun with the development of the solid-state lighting in the form of light-emitting diodes (LEDs). LEDs are now available with up to 42 lm/W efficiency and
1.2W per light source and higher outputs are expected. LEDs are assembled in arrays of 4 individual LEDs. Their light output already rivals a 20W incandescent lamp in such arrays. It is expected that, within a few years, LEDs will be used in standard lighting systems, thus competing with the more traditional technologies. As there are no filaments, electrodes or moving mechanical parts, manufacturers predict a very long lifespan.

**Efficient lighting in our offices**

It is estimated that only 25% of office lighting is fully efficient today.

In an office environment, major energy savings are possible through the use of efficient luminaries combined with efficient lamps. The better quality of light in the work place is an additional bonus.

Efficient lamp systems are one source of savings. Efficient use is another, and occupancy sensors and behavioural changes can further reduce the consumption of energy in office lighting.

**Industrial and public lighting**

In an industrial environment, energy used for lighting represents on average 5 to 10% of total energy consumption. Public lighting consumes more than 1% of electricity use in some European countries.

For outside use, metal halide lamps are among the most energy-efficient sources of white light available today (up to 100lm/W).

In public lighting, the available budget for investment and the rules for public procurement are key factors for the success of energy-efficient street lighting. Although the technological evolution in street lighting is impressive, renewal rates are today quite low, at only 3% per year.

Some policy measures to promote energy-efficient lighting:

- Fully enact the EU Council proposal to introduce energy efficiency requirements for office and street lighting from 2008 and to phase out inefficient incandescent lighting in most domestic applications from 2009
- Build awareness campaigns
- Introduce labelling schemes
- Introduce fiscal and tax incentives, remove tariff barriers on imported energy efficient lamps where appropriate
- Introduce energy efficiency standards in public procurement rules

### 2.2 Heating and Cooling with Heat Pumps: electricity to lower energy use and CO₂ emissions

Heat pumps extract ambient renewable heat or cold to heat or cool houses and commercial buildings or for warm water supply. Heat pumps are also used for drying and heating in the food industry and for drying cloth in laundries.

A heat pump uses an electric compressor to “pump” heat from one place to another. By pumping heat from outdoor air, soil or groundwater into the house, a heat pump can produce two to six times more heat per kWh than an electric radiator. All heat pumps have the same basic key components: a compressor which does the actual “pumping”; an indoor coil, which heats or cools circulating house air; an outdoor coil in the heat source which supplies heat to the system; and copper tubing that circulates refrigerant fluid between the indoor and outdoor units. The energy extracted from the environment is a renewable energy source.
In Southern countries, air-to-air heat pumps are more common. In the cooler countries of northern Europe, air-air heat pumps are not efficient in heating mode and so “geothermal” or “ground source” heat pumps are used. These comprise a “water-to-water” heat exchanger tapping the heat from the fluid in the ground to an in-floor radiant heating system or baseboard units, similar to a water-circulating central heating system.

A significant advantage of any type of heat pump is that its cycle can be reversed in summer to supply air conditioning to the house. In cooling mode, the indoor and outdoor elements switch functions. The house now becomes the heat source and the outdoor element - air heat exchanger, ground loop or water well - becomes the heat sink.

**FIGURE 4: SCHEMATIC OF A TYPICAL GROUND-SOURCE HEAT PUMP INSTALLATION (EUROPEAN HEAT PUMP ASSOCIATION)**

The most important characteristic of a heat pump is its coefficient of performance (COP). COP is the ratio of useful energy delivered over the amount of final energy input into the heat pump. The COP values of an efficient system are typically equal to 4, meaning that 4 units of energy are delivered for every unit input to the system. COP values in Japan are already higher than 5. The best heat pumps reach a COP of 6.8.

However not all heat pump installations on the European market meet the above efficiency standards. Europe currently imports large quantities of cheap and inefficient air conditioners with COP values lower than 2. They waste valuable primary energy and should be restricted by minimum efficiency standards.

Heat pumps, unlike gas and oil heating, not only have zero CO₂ emissions at the point of use, but also perform better in a well-to-wheel analysis. As a simple calculation example, let us consider a condensing natural gas-fired boiler, with a theoretical efficiency of 100%, used to heat our home. As an alternative, let us assume that the same natural gas is used to generate electricity in a state-of-the-art combined cycle power plant, which, including electricity transmission grid losses, has an overall efficiency of 50%. That electricity is then put into a heat pump system at a COP of 4. The 50% efficiency now becomes 200%. Only half the volume of natural gas is needed to heat the house and hence only half the volume of CO₂ is emitted. But the savings potential does not end there: in combination with a low-carbon electricity mix, as envisaged in the Role of Electricity scenario, CO₂ emissions will only be a fraction of the emissions in a standard home heating system.

Figure 5 illustrates the reduction of CO₂ emissions and oil and gas use that can be obtained with a heat pump for heating a typical house (30,000 kwh heat load). CO₂ emissions for electricity correspond to the Role of Electricity scenario. No advance in heat pump COP is taken into account although there is certainly scope for this. Oil and gas boiler efficiency is assumed in this figure as 100% to allow for the maximum advance of boiler efficiency (the current market average for a new condensing gas boiler is 88% efficiency).
Ground-source heat pump systems are costly and the cost of the ground loop will often exceed the cost of the heat pump itself. Payback can, therefore, be difficult to obtain. Energy savings will deliver the major part of the cost savings. In comparison to oil heating, heat pumps do not need infrastructure or valuable space for oil storage, which offers a second source of cost saving.

These two savings combined will however not always compensate for the larger initial investment cost and some form of support will be needed to enable the market to take off and eventually deliver price reduction through mass production. Nevertheless, the market is developing rapidly in some countries, such as Sweden, Finland, Switzerland and Austria – all with annual growth of some 10% or more. Other countries like Germany, Belgium and France show a large potential, but have not yet been able to develop a self-sustaining market.

In the most active countries, the expected annual growth of the heat pump market for the 2000-2010 period is in the 15-40% range.

Some policy measures to facilitate the breakthrough of heat pumps:

- Fully recognising the renewable nature of the energy extracted from the environment and integrating this into RES policies, with the proviso of a sufficiently high COP value
- Minimum COP standards for import and for a sufficiently high sales of air conditioners
- Awareness campaigns and investment support
- Proper training for installation personnel

**2.3 Household & Office Appliances**

Our homes are being filled with TVs, DVD players, mobile phones, computers and their peripherals, plus other communication appliances, while the use of office equipment in our work environment...
steadily increases and it is generally accepted that the demand for information and communication services and technologies will increase sharply.

The fastest-growing area of residential electric end-use is projected to be in consumption of standby power. This is the consumption of electricity by appliances that are turned off or are in a low power-consumption mode, such as standby, hibernate, sleep modes, etc. The present total EU power consumption by home consumer electronics on stand-by is estimated at about 36 TWh and is forecast to rise to 62 TWh by the year 2010. Set-top boxes, hi-fi systems and DVD players demand over 4W of standby power. Other electronic devices typically consume 2-4W of standby power.

The standby power requirements of most appliances can be reduced to less than 1W by using a simple electronic circuit, and The International Energy Agency’s One Watt programme aims to make this best practice. At European level, the European Commission has since 1994 been investigating the electricity consumed through standby losses of TVs and VCRs. As a result, over the last decade significant progress has been made, reducing standby power loss for TVs from 6.18W to 1.75W over the 1996 to 2003 period, and for VCRs from 6.64W to 3.53W. However, significant further efforts need to be made to reduce unnecessary electricity consumption in this area.

Policy measures to further promote energy-efficient household and office appliances include:
• Labelling
• Standards, especially for standby power supply
• Information and awareness campaigns

2.4 Efficient Motor Systems

Motor-driven systems are by far the most significant electric load in the EU industrial sector, accounting for approximately 65% (688 TWh) of the electricity consumed. In the tertiary sector, motor drives represent about 38% of electricity consumed. Compressed air, pumping or ventilation systems represent around 60% of motor loads. Other important uses include materials-processing (mills, mixers, centrifugal machines, etc.) and materials-handling (conveyors, hoists, elevators, etc.) applications.

A motor system consists of the electric drive itself, sometimes a Variable Speed Drive (VSD), and the driven load. Typically, the overall efficiency of the motor system depends on a combination of the three elements.

The application of high-efficiency motor technologies, in particular energy-efficient motors and Variable Speed Drives, could save about 166 TWh by 2030 in the EU25.
Most (as high as 60%) of the efficiency gains are on the mechanical side of the application part of the motor system. Replacing or leaving out mostly mechanical components between the motor and the load can dramatically improve system-efficiency.

**Energy saving through variable speed drives**
The use of motor speed control instead of mechanical control can save up to 30% of the energy input. A third of all new motors sold in 2004 were variable speed motors.

Motor speed controls are particularly attractive in applications where there is a variable fluid flow. In many centrifugal pump, fan and compressor applications, mechanical power increases roughly as a cube of the fluid flow. Only half of the power at full load is required to move 80% of the nominal flow. Centrifugal loads are therefore excellent candidates for motor speed control.

**Energy saving through the use of high efficiency motors**
Until the 1970s, motor designers minimised the use of raw materials (copper, aluminium and silicon steel). The motors had lower initial costs and were more compact than previous generations of motors but, due to their low efficiency, running costs were higher. By the mid-1970s, most large motor manufacturers had begun offering a line of energy-efficient motors alongside their standard efficiency motors. Efficient electric motors (EEMs) typically show 30-50% lower losses than the equivalent standard motors. Due to their lower...
rotor resistance, EEMs normally have lower starting torque than standard motors. EEMs normally carry a price premium of around 20-25% in relation to standard motors.

Some suggested policy measures to promote energy-efficient motor drive systems:

- Energy auditing and information to industry, especially to SMEs
- Standards and best practice guidelines

2.5 Rail Transport, an energy-efficient way to move

It is well known that moving people around via public transport generally uses much less energy than private transport. Development of public transport will therefore almost always have a positive impact on total energy use and consequently on total greenhouse gas emissions. In addition to its advantages over private transport, rail transport also has particular advantages over road-based public transport – notably its ability to use electrified systems, plus the low friction of steel wheel on steel rail. It also offers high speeds and good levels of comfort. In Europe, electrified rail transport (railways, trams and metros) already accounts for a significant percentage of passenger transport - an average of 7% across the EU-25 in 2004 - and 16.5% of inland freight transport. 51% of all railways in the EU-25 are electrified. In some countries, much higher proportions of the network are electrified, for example 83% in Belgium, while other countries such as Finland continue to slowly electrify their existing networks.

Electrified rail transport enjoys significant advantages over its diesel-driven equivalent. It is not dependent on imported oil and is able to use an energy source that offers lower carbon emissions, and as carbon emissions from electricity continue to decrease, the benefits of electrification will become even more apparent. Electrified railways also offer the possibility of regenerative braking, no local air pollutant emissions, better acceleration performance and a better image with the customer. Making a comparison with road transport, EU-25 figures show passenger railways consuming only 16 tonnes of oil equivalent (toe)/Mn passenger-km compared to 37.8 toe/Mpkm for private car transport. Again the figures for rail freight transport show an even stronger advantage over road transport: 5.5 toe/Mn tonnes-km for rail freight compared to 72.4 toe/Mtkm for road truck transport.

High-speed railways, running at up to 330 km/h, have developed rapidly in Europe in the past 20 years and offer real potential to replace much short-haul air transport, particularly on routes up to 600km, involving less than 3 hours rail travel. Their development is already encouraging and should be further promoted, with continuing efforts to improve cross border interoperability, as these links are increasingly international (e.g. Frankfurt-Paris, Brussels-Amsterdam, etc). The delays in fully implementing the European Rail Traffic Management System (ERTMS) have been disappointing in this respect.

There is considerable potential for the efficiency of electric rail transport to increase further. At the same time, associated CO₂ emissions will fall in line with reduction in the carbon intensity of electricity – the Role of Electricity scenario suggests the CO₂ intensity of power generation will decline by about 65% by 2030 (see section 4, Modelling). Moreover, many measures can be applied to reduce energy...
The Role of Electricity

consumption per se. Some railway companies have already put in place programmes to reduce energy consumption, German rail company Deutsche Bahn for example achieving just under 15% reduction in energy consumption on long distance passenger transport between 1990 and 2004\(^3\). Some examples of ongoing and possible future measures to improve the energy performance of railways are:

- Improving energy metering to better monitor and incentivise lower energy consumption
- Better traffic management – e.g. reducing stops/starts by freight trains which increase energy consumption significantly compared to constant running speeds
- Reducing trains’ auxiliary energy consumption – i.e. heating, air conditioning and lighting, and reducing “standby” consumption when not in use
- Greater use of regenerative braking – returning energy from braking back to the network
- Improving motor and power control technologies to increase drive train efficiency
- Improving train aerodynamics and reducing weight

Such measures are already being advanced through projects such as the Rail Energy project led by the Union of Railway Equipment Manufacturers (UNIFE) and the PROSPER project of the International Union of Railways to define environmental procurement criteria for trains\(^4\).

Urban electrified rail systems such as tramways and metros offer fast and attractive transport in urban areas. Implementation of city toll systems for private road transport will further enhance the popularity and development of these systems. Meanwhile, the development of tram-train concepts and regional express railway (RER) systems allow commuters from outlying towns car-free access to the city.

Despite the advantages enjoyed by rail transport, its modal share of transport has declined in recent years, particularly in the new EU member states. Modal share of passenger transport fell from 6.3% in 1995 to 5.8% in 2004. The decline in rail freight modal share has been steeper – from 19.5% in 1995 to 16.8% in 2005\(^5\). While recognising the positive approach of the European Commission towards the development of rail transport, through the 3\(^{rd}\) Railway Package, the 2001 Transport White Paper, and the creation of the European Railway Agency, further efforts are clearly required to develop rail transport. The development of high-speed rail has, however managed to stabilise or slightly increase rail modal share in countries such as France.

Policy measures to incentivise development of rail transport efficiencies include:

- Removal of rail network “bottlenecks” which prevent rail traffic growth, particularly in freight transport from ports
- Greater development of urban public transport systems (the 2007 Urban Transport Green Paper is a positive step here)
- Development of policy measures and standards to improve the energy efficiency of railways (the upcoming Strategic Energy Technology Plan provides such an opportunity)

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\(^3\) Deutsche Bahn (2005) Environment key data

\(^4\) UIC – International Union of Railways (2005) Final report of the PROSPER project (DB and IZT consultants)

- More intermodal links between road and rail to encourage transfer
- Inclusion of aviation in the EU emissions trading system to drive the shift from short-haul air travel to high-speed rail
- Urgent measures to maintain the modal share of rail in new member states where a rapid shift to road transport is occurring
- Taxation of road transport, particularly freight transport, e.g., through EU-wide tolling system, to encourage the shift to railways

2.6 Plug-In Hybrid Electric Vehicles to save energy and prime hydrocarbons

Transport is a fast-growing market and could, under business-as-usual conditions, increase its energy consumption by over 10% and would remain the largest consumer of energy by 2030. Given its near total dependency on oil, road transportation is a key segment for energy efficiency and carbon-reduction action. More efficient drives and alternative drives that do not use fossil hydrocarbons must be developed.

Hybrid fuel engines always operate near optimum, even in stop-start city traffic, and cars fully recover braking energy. They are becoming part of the market, given momentum by environmental awareness or by more restrictive rules in the city environment.

The plug-in hybrid vehicle (PHEV) is a logical development of the hybrid car. It has a larger battery, which is charged as far as possible from the electricity grid, not by the motor car itself, allowing the use of grid electricity for typical city commuting and limiting the need to revert to gasoline for longer distance journeys.

PHEVs have a double advantage over the classic internal combustion engine. The combination of the electric motor with the ICE improves fuel efficiency, while the plug-in option allows a full electric drive. The full electric drive will allow the user to cover urban journeys with electricity from the battery. The electric-only range of the PHEV can be from 10km to over 100km depending on the battery capacity. However, unlike the fully electric vehicle, the PHEV has unlimited autonomy using the ICE.

The plug-in hybrid car has the ability to substantially reduce CO\textsubscript{2} emissions and improve the energy efficiency of road transport, while also reducing oil dependency, without sacrificing the comfort and safety requirements of passengers. In battery mode, final consumption will be less than half the consumption of the standard hybrid vehicle and primary premium fossil fuel will be substituted by the portfolio of energy sources used for electricity production.

In combination with a low-carbon electricity mix, synergies can be put to work to significantly reduce both CO\textsubscript{2} emissions and oil use.
Some characteristic values:
- A hybrid electric petrol vehicle shows similar consumption to a diesel car, i.e. 20% less than a petrol car
- Final consumption of a plug-in hybrid petrol car, in full battery mode, will be about 50% of the consumption of a hybrid petrol car

**FIGURE 10: SCHEMATIC OF PLUG-IN HYBRID SHOWING USE IN ALL ELECTRIC AND HYBRID MODE (TOYOTA)**

**FIGURE 11: COMPARISON OF THE CO₂ EMISSIONS OF AN ICE PETROL CAR, A HYBRID CAR AND A PHEV (PREDICTED TREND TO 2030)**
Hybrid cars - and PHEVs even more so - are more expensive than the petrol car. A hybrid car today carries a cost surplus of about €8,000. However, the president of carmaker Toyota has announced that the price surplus must be reduced by 50%, thus coming down to €4,000. A PHEV will cost an additional €3,000 to €4,000 (assuming the battery capacity to provide an electric-only range of 30km). An approximate current estimate is that each additional 10km of electric range will cost about €1,000 provide the battery capacity required.

The PHEV could obtain a market share of 8-20% by 2030, the higher figure being envisaged in an environment characterised by more stringent emission rules and high oil prices as opposed to the business-as-usual case. Plug-in hybrids will also gain a share in the market for commercial vehicles, in particular for urban delivery vehicles.

Some policy measures to promote Plug-In Hybrid Vehicles:
- Support R&D and demonstration, in particular on low-cost, long-autonomy battery technology – especially using alternative materials such as lithium phosphate battery
- Reduce the investment handicap through appropriate tax measures
- Enact emissions-reduction policies for road transport

2.7 The continuous quest for energy efficiency: concluding remarks

The core element is a holistic view of energy efficiency:
- Greater energy efficiency means cost reductions and lower environmental and health impacts, hence also an improvement in Europe’s competitiveness.
- Electricity can play a crucial role in this respect. On the one hand there is considerable scope for improving the efficiency of existing electric applications. On the other hand electricity can replace less efficient technologies and substitute for primary hydrocarbons.

However, managing the demand side is a serious challenge. The European Commission has already taken up this challenge by formulating:
- An Action Plan on Energy Efficiency
- A Directive on Energy End-use Efficiency and Energy Services
- A Proposal for a 130g/km limit on average CO₂ emissions of cars

The implementation of more energy efficiency measures on the demand side is however being hindered by a number of constraints that must be overcome: entrenched customer habits; a lack of customer awareness of the advantages of certain technologies; and the high initial investment barrier for new, more efficient technologies.

If demand management is to produce tangible results and achieve the desired energy efficiency gains, some targeted policy measures will be required:
- Selected incentives to reduce the initial investment costs of more energy-efficient equipment and make them more competitive and accessible: this is particularly true for heat pumps and PHEV
- Awareness campaigns in collaboration with the relevant sectors designed to explain the benefits of new technologies and the rationale for consumers to change their behaviour: this is particularly true for energy-efficient light sources and public transport
- Selective labelling schemes and specific stand-
ards for equipment (e.g. maximum standby power losses, standards for consumer electronics, air conditioners and heat pumps)

We believe that the findings of this project, if implemented jointly by policymakers, industry and society, can deliver significant energy savings and reduce CO₂ emissions. This combined effort will also foster the deployment of more innovative and competitive technologies, not only contributing to a more competitive economy, but also creating opportunities for European industry to sell its products and expertise in the global market.
3 Electricity Supply: Towards Low-Carbon Power Generation
Along with developments in demand-side technologies, future progress in power generation technologies is of paramount importance on the path towards a sustainable electricity system. Technologies providing CO₂-free or CO₂-low electricity are of key importance, alongside improvements in thermal efficiency and the introduction of technologies to capture and store carbon dioxide.

Power generation plants convert primary energy sources into electricity. Three generic conversion processes can be distinguished:

1. Transformation of mechanical energy into electricity: all thermal, wind and hydro power plants employ the same principle, whereby a turbine rotates a generator
2. Direct conversion of solar radiation into electricity by photovoltaic cells
3. Electrochemical conversion in fuel cells

3.1 Power generation technologies now and in the future

Europe’s current electricity generation portfolio is varied, with significant differences between the supply portfolios of different Member States. Following a general description of the current technologies, this report provides a prospective analysis of power generation technologies, looking into their development potential within a time horizon of 2030-2050:

- **Fossil-fuel fired power plants**, either with or without carbon capture technology. This includes steam cycle hard coal and lignite power plants, Integrated Gasification Combined Cycle (IGCC), Oxyfuel power plants, and Combined Cycle Gas Turbines (CCGTs)
- **Renewables**: onshore and offshore wind energy; various types of hydropower plants - run-of-river, pumped storage and storage; biomass power plants; solar thermal; photovoltaic and geothermal
- **Nuclear power plants**: light water reactors, fast breeder reactors, and high temperature reactors
- **Small-scale generation**: fuel cells, micro gas turbines, Stirling engines and internal combustion engines

For each technology an estimate was made, to the 2030 and 2050 horizons, of key investment, operation and energy-efficiency parameters and emissions values as input to the economic model used for scenario analysis.

The physical parameters and the cost figures of the various generation technologies are based on sound data, derived from real projects and the generators’ experience in planning, constructing and operating power plants. They are embedded in international and European reports (IPCC, the IEA World Energy Outlook 2006 and the findings of the EU’s Technology Platform on Zero-emission Power Plants [TP ZEP]. Transport and storage of CO₂ have not been addressed in this part of the project. However cost figures for transport and storage are integrated into the PRIMES database for further modelling purposes. TP ZEP has also developed a roadmap for transport and storage of CO₂.
### 3.2 The development of fossil-fuel fired power plants

Large-scale power plants form the backbone of Europe’s power generation fleet. A major part of these are thermal plants fired by fossil fuels. The development of these technologies is therefore a crucial element in ensuring that Europe’s power generation can improve its sustainability for the future.

Substantial reductions in CO₂ emissions can be achieved by improving the efficiencies of conventional power plants and taking advantage of the significant economies of scale. By employing carbon capture and storage (CCS) in addition, it is possible to make the use of fossil-fuel power plants virtually CO₂-free.

**Steam cycle coal and lignite plants** are in use all over Europe. In these plants, coal and lignite are converted into electricity by burning the fuel and running a steam turbine to drive an electricity generator. A key factor in improving steam cycle plants is the potential to increase steam temperature, which depends on the development of new metal alloys able to sustain the higher temperatures. An increase from the present 560°C degrees to temperatures around 700°C is expected by 2020, driving up plant efficiencies from roughly 43% today to approximately 52%, and consequently reducing the specific CO₂ emissions by 35%.

One of the main developments is **Integrated Gasification Combined Cycle (IGCC)**. Currently only a handful of IGCC plants are in commercial operation in the world, but the technology represents significant potential to improve the thermal efficiency of the conversion process. Another advantage of IGCC is its suitability with CCS technologies (see below) prior to combustion. It is estimated that by 2030 the thermal efficiency of IGCC plants could reach 52%. This, coupled with pre-combustion carbon capture, would enable large-scale power generation based on solid fossil fuels to emit virtually no CO₂.

**Combined Cycle Gas Turbines (CCGTs)** is their low capital cost, which makes CCGT technology particularly attractive in the liberalised electricity market. CCGT is currently the most efficient thermal conversion technology, with efficiencies reaching up to 57% at present and over 60% by 2030. Combined heat and power, in the presence of a stable heat load and if properly dimensioned, leads to additional energy savings.

**FIGURE 13: CO₂ REDUCTION IN COAL-FIRED POWER PLANTS (VGB POWERTECH)**
3.3 Special focus: carbon capture and storage

CO₂, the most important anthropogenic greenhouse gas, is produced in every process in which carbon is burned. CO₂ emissions are thus a major issue for any use of fossil fuels, whether in transport, industry or power generation. “De-carbonising” electricity production from large-scale fossil-fuel power plants is therefore a tempting political and technological goal. Improving thermal efficiencies alone will help, but will not enable the total removal of CO₂ emissions.

One of the most promising technology paths for the future is carbon capture and storage (CCS), in which the CO₂ from power plants would be captured at the plant and then transported and injected underground. This will require the development of new solutions. Many of the required technologies actually already exist in smaller-scale industrial applications, but the main challenge for electricity production is to develop them for secure and economic use by large thermal power plants.

Three main technologies for carbon capture are envisaged:

- **Pre-combustion capture** is linked to IGCC technology, whereby coal is gasified into a synthetic gas (“syngas”) before combustion. CO₂ is removed from the syngas and the remaining hydrogen then combusted in the IGCC plant.
- **In oxyfuelling**, the fossil fuel is combusted in pure oxygen rather than air. The resulting flue gas has a very high CO₂ concentration, which enables it to be captured at the plant.
- **In normal post-combustion capture**, CO₂ is removed from the plant’s flue gases at end-of-pipe. Various options exist for the removal process, depending on the composition and volume of flue gases to be treated.

The extracted CO₂ is then transported for storage underground or used for enhanced oil or gas recovery.

**FIGURE 15: CO₂ CAPTURE AND STORAGE TECHNOLOGIES (VGB POWERTECH)**
One disadvantage of CCS is that the processes are very energy-intensive and will therefore impose an energy penalty on the plant. Compared to the efficiency figures listed above, it is estimated that plants equipped with (state-of-the-art) CCS will show the following efficiencies by 2030 (with the respective efficiencies of plant without CCS shown in brackets):

- Steam cycle hard coal plant: 40% (52%)
- Steam cycle lignite plant: 44% (54%)
- IGCC 43% (52%)
- Oxyfuel 42% (not applicable without CCS)
- CCGT 57% (62%)

This energy penalty is significant and it is therefore vital both to improve the efficiencies of conventional power plants and to reduce the energy penalty of CCS technologies.

CCS therefore represents a significant challenge for research and development. While many technologies used for CCS (gasification, capture technologies, etc) are already available, they have not yet been developed on an industrial scale. This represents a challenge not only for the industry and equipment manufacturers, but also for the public authorities. EU research programmes are a key instrument to kick-start a number of large-scale demonstration projects.

A number of regulatory issues also await solution before full-scale deployment of CCS can happen. These include the treatment of CCS under the EU Emissions Trading Scheme and the regulatory and liability aspects of CO₂ storage. Public acceptance is also a major issue, which will require efforts from all involved parties.

The European Commission, in its communication on An Energy Policy for Europe, proposes the establishment of a favourable regulatory framework, the recognition of capture and storage in the Emissions Trading Scheme, and endorses the industry’s commitment to the construction and operation by 2015 of up to twelve large-scale demonstration plants in commercial power generation, as set out by TP ZEP. In addition, the Commission believes, on the basis of existing information, that after 2020 all new coal-fired plants should be fitted with CO₂ capture and storage, and existing plants progressively retrofitted.

Setting a timescale for mandatory deployment of CCS seems premature before real industrial demonstration. Nevertheless, analysis in the Role of Electricity project confirms that carbon capture and storage is a key technology option which holds the promise of continued use of fossil fuels with negligible CO₂ emissions beyond 2020.

**FIGURE 16: INVESTMENT COST FOR FOSSIL-FIRED PLANTS IN 2005 AND 2030 WITHOUT CCS, AND PROJECTED FOR 2030 AND 2050 WITH CCS**
As the use of CCS will drive up the cost of producing electricity, the price of CO₂ allowances will constitute the main driver for investment in CCS facilities in the future.

### 3.4 Renewable Power

Renewable energy sources are widely used for electricity and heat production. Many technologies are mature and competitive, or becoming competitive, such as hydroelectricity, biomass combustion and windpower. In the more distant future, we can envisage some novel technologies such as geothermal energy and wave and tidal power being used more widely. However, many smaller-scale renewables applications still require economic support in the marketplace.

Renewable energy sources represent many significant advantages compared to the use of fossil fuels. They emit no CO₂ in operation and favour domestic or local solutions, consequently in principle improving supply security. As European companies are global market leaders in many RES technologies, RES use can also make a significant impact on Europe’s international competitiveness.

**Hydropower** represents by far the largest share of existing RES capacity. Large hydropower is competitive, with excellent efficiencies: depending on the plant, between 75-90% of the energy input can be converted into electricity. On the downside, large hydropower has a high capital cost and it is no longer possible to significantly increase large hydro capacity in Europe for environmental reasons.
Wind power, both onshore and offshore, has experienced tremendous growth globally, and especially in Europe, in the past decade. Wind turbines are built to transform the energy of wind into electricity through the rotation of the turbine, which drives the power train that in turn transfers the power to the generator. Wind turbine efficiencies are presently around 43-44% and they will increase modestly - to some 46-47% - by 2030. While wind-power enjoys strong support, its impact on the operation of power grids due to its intermittency remains a key challenge for Europe.

**FIGURE 21: INVESTMENT COST OF RENEWABLE ENERGY PLANT IN 2005 AND PROJECTED FOR 2030/2050**

<table>
<thead>
<tr>
<th>Investment Cost</th>
<th>€/kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro 544kW</td>
<td>1650</td>
</tr>
<tr>
<td>Hydro Storage</td>
<td>1200</td>
</tr>
<tr>
<td>Wind Offshore</td>
<td>1250</td>
</tr>
<tr>
<td>Biomass 3A</td>
<td>1800</td>
</tr>
<tr>
<td>Biomass Cof</td>
<td>2500</td>
</tr>
</tbody>
</table>

Note: The costs of biomass co-firing are the costs in addition to the existing fossil-fired plant which is enabled for co-firing - the number of kW installed for co-firing is deemed to be in proportion to the percentage of biomass used out of the total fuel used in the plant (for example, if 30% of the fuel for a 1000MW plant is biomass, 300kW of Biomass capacity is said to be installed).

Biomass may be converted into energy in several ways, most often by direct combustion. As biomass fuels may contain elements harmful for engines, only external combustion technologies can be used. In stand-alone firing, biomass plant efficiencies are relatively low, currently in the region of 32%, and are not projected to rise any higher than 35% by 2030. In co-firing however, the use of biomass is much more efficient, currently reaching approximately 45%, with forecasts of 50% by 2030. The use of biomass in co-firing also shows a better economic return.

Other RES technologies include solar thermal, solar photovoltaic energy, plus geothermal, wave and tidal energy. They represent a large potential for the future, but will require very high technological and economic development if they are to attain a significant share in Europe’s power generation mix.

### 3.5 Nuclear Power

Nuclear power plants, like fossil-fuel-based thermal power plants, employ a steam turbine to rotate the electric generator, but in nuclear plants, heat production takes place via a fission reaction instead of combustion. Nuclear technologies have seen gradual efficiency improvements and further potential exists.

The main advantage of nuclear electricity is that it produces no CO₂ in the normal operation of the plant, and the amounts are negligible even on the basis of a full life-cycle analysis. Therefore the use of nuclear energy has the market advantage that it bears no additional CO₂ cost. Moreover, fuel costs represent only a small fraction of the total cost of electricity. The counterpart to these relative advantages is the high investment cost plus the cost of plant decommissioning and the handling of nuclear waste and spent fuel, which all add to the cost of producing electricity.
After a period of political reluctance, nuclear energy is now once again becoming a more accepted option, even in some of those countries that decided to phase out nuclear power in the aftermath of the Three Mile Island accident in 1979 and the Chernobyl disaster in 1986.

Figure 23: Nuclear Technology Generations (VGB PowerTech)

Figure 24: Investment Costs for Different Nuclear Plant Technologies in 2005 and Projected for 2030/2050

Figure 25: Efficiency of Different Nuclear Plant Technologies in 2005 and Projected for 2030/2050
3.6 Steady development of technologies

Europe's electricity production portfolio is varied, and many different technologies are employed. Looking to the future, technological changes and innovations in the generation portfolio will create additional primary energy savings and lead to lower CO₂ emissions. On the technology front the following conclusions emerge:

As a whole, Europe employs a relatively balanced mix of technologies for electricity production. CO₂-free power generation is already available today. Renewable energy sources and nuclear energy are in place in Europe and 45% of all electricity generated in the EU-25 is CO₂-free. Classical conversion technologies are becoming more efficient. The resulting progress reduces costs and contributes to sustainability. Examples of a further increase in conversion efficiency in generation are:

- Coal-fired generation: coal will be converted at 46% efficiency or even 52% in 2030, up from values as low as 34%.
- Gas-fired generation: gas will be converted in combined cycles at 58% or even 61% in 2030, up from under 40% in an open circuit gas turbine.
- Nuclear efficiency will increase by a further few percentage points with current technology. Efficiency can improve further with new higher temperature technologies.

Carbon capture and storage is an emerging technology that will enable us to combine the use of fossil fuels for large-scale electricity generation with low-CO₂ emissions. With the necessary R&D and demonstration efforts, the technology is expected to become available for commercial use shortly after 2020. Losses in energy efficiency are expected to decline substantially over time.

Our analysis demonstrates that, under the right policy framework, the transition to a low-carbon power generation mix is technically and economically feasible. The analysis also demonstrates that a low-carbon generation portfolio can be based on secure energy sources. Under the Role of Electricity scenario, the average CO₂ content of European electricity production further decreases from 410 gCO₂/kWh in 2005 to 130 gCO₂/kWh in 2030.

A key enabling factor in the transition towards a low-carbon power system is the price of CO₂ allowances in the European markets. Long-term visibility for the CO₂ price will constitute the main driver for the development of and investment in low-carbon or carbon-free technologies in the future.

Electricity producers have in general built their business strategies on a mix of different primary energy resources and different technologies, an approach which facilitates the management of both technological and political risk. Using a portfolio of technologies can mitigate the risk of generic problems arising from the introduction of new technologies or materials, while political risk can also be minimised by using a mix of technologies and primary energies from different regions.
4 Energy Modelling and scenarios
4 Energy Modelling and scenarios

4.1 Methodology

The aim of the modelling work carried out within the Role of Electricity project was to quantify long-term scenarios for the future evolution of the energy demand and supply sectors in Europe. For this purpose, the project partners used the PRIMES energy system model for detailed projections up to 2030 and the Prometheus world energy model for a consistency analysis of world energy markets and longer-term projections up to 2050.

The projections based on the PRIMES model were carried out with a high level of detail, on a country-by-country basis for all current and potential future members of the European Union (EU-27 plus Norway, Switzerland, Turkey). This report shows only aggregate results for the EU-25.

The Prometheus model has analysed endogenously the formation of world energy prices. It treats Europe as a single region but views it as part of a global, worldwide energy system and market.

The databases of both models have been considerably updated and supplemented with data and information provided by the other two teams working on the supply- and demand-side sections of the project, applying a bottom-up approach. These teams provided technical and economic estimates of the future evolution of technologies related to power generation and consumers’ use of electricity.

A scenario is composed of a set of assumptions and the consequent results of those assumptions worked out through the model. The energy system models start by taking as given a future path of economic growth and then focus on energy demand and supply and the interactions between them that influence the formation of energy market prices. The models do not however take account of any feedback effects from energy on overall economic growth.

The models represent multiple economic sectors and multiple energy forms, commodities and market. They also represent specific energy technologies in an explicit manner. The future evolution of energy technologies is represented dynamically by taking into account that their technical and economic features evolve over time and are influenced by the degree to which they penetrate the markets. The potential of all technologies and energy forms or resources is represented as nonlinear functions which express possible diminishing returns, possible exhaustion of potential or, on the other hand, positive externalities such as learning by doing.

The Prometheus model determines endogenously the future evolution of world fossil-fuel prices as a result of resource potential and the dynamic interactions between demand and supply. The PRIMES model takes as given the world fossil-fuel prices and focusses on energy-conversion markets in Europe, such as the electricity market, for which it determines market equilibrium prices endogenously. The projections of the two models are linked together through a model-calibration procedure, which ensures consistency in the combined use of the models.

Both models calculate emissions of pollutants and greenhouse gases from energy conversion and use. Policy instruments for emissions-limitation are also represented, including emissions caps, taxes and trading of emission allowances. Similarly, a series of energy-related policy instruments is represented, including on energy efficiency and technology standards, taxes and subsidies, support schemes for renewable energy sources and cogeneration, etc.
As is standard practice, the models are first used to quantify a baseline scenario and then to quantify alternative policy-oriented scenarios. The baseline scenario serves as a reference against which the alternative scenarios are assessed. This procedure serves to evaluate the implications and cost-effectiveness of policies and changes that are reflected in the alternative scenarios.

4.2 Baseline Scenario

The baseline scenario, which reflects business-as-usual trends, is very similar to that used in the last update of the European Commission Energy and Transport “Scenarios on key drivers” (2006). Dynamic trends and changes are reflected, but their evolution is assumed in this scenario to result only from existing (ie pre-2004) policies and trends, without any consideration of new policy instruments or policy targets. It is not a forecast, but a simulation of what the limitations of the system would be if it simply continued to evolve without reacting to perceived failures or adverse effects. Hence, baseline assumes that the current EU Emissions Trading System (ETS) continues to operate, inducing a constant carbon value of €5/tCO2 which is applied as an opportunity cost on all uses of fossil fuels in proportion to their emission of CO2, but it does not assume any further measures that the European Union might enact in order to reduce emissions of greenhouse gases in pursuit of the Kyoto climate change targets, pre- or post-2012.

The assumptions for economic growth are optimistic: Europe succeeds in growing at an average rate of 2% per year until 2030 but then growth slows in the longer term to approach 1% per year until 2050. The European economy progressively changes its structure as sectors with higher value-added grow more than sectors that are heavily intensive in terms of energy and materials. European demographics are rather stable. Worldwide economic activity is projected to grow steadily at a rate of 3% per year until 2030 and by 2.2% in the longer term. Year 2012 is a turning point as emerging economies, such as China and India, start to consume higher quantities of energy than the OECD.

The baseline scenario reflects an energy pathway influenced by relatively high oil and gas prices (Figure 26) rising substantially higher than forecasts of three or four years ago. Oil prices are projected to stabilise in the short-medium term at a level slightly lower than the 2005-2006 peak and to start rising again in the long run, reaching 46€/2005/bbl in 2030 and almost 80€/2005/bbl in 2050. These long-term oil price trends reflect resource constraints, continuous growth of global energy demand and increasing dependence on non-conventional oil, which has high extraction costs.

Natural gas prices are projected as tightly linked with oil prices. This is not only related to existing long-term gas procurement contracts but also a result of market dynamics, since gas is potentially a substitute for oil and the demand elasticity of gas is high.

Coal prices are projected to rise at far lower rates than oil and gas as a result of high coal resources and more favourable geopolitics. This implies that

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4 All monetary figures refer to constant Euros of 2005
the competitiveness of gas vis-à-vis coal steadily deteriorates: the gas-to-coal price ratio, at 1.5 in the 90s and 2.5 in 2006, approaches 3 before 2030 and then reaches the value of 5 in 2050.

**Figure 26: Import Prices of Hydrocarbons in Constant Currency**

The European baseline outlook (Figure 27) shows total primary energy requirements steadily decoupling from economic growth: energy grows by 0.3% per year as a result of overall energy intensity of GDP declining by 1.7% per year. This is in line with historical long-term trends and is a combined effect of structural changes in the economy, saturation and technological progress. Electrification in energy demand is projected to continue under the Baseline scenario, reflecting past trends: electricity demand grows by 1.3% per year and electricity's energy market share rises steadily from 17% in 1990 to reach 25% in 2030. This trend reflects the fact that electricity drives technological progress, comfort and new economic growth in Europe.

Final energy demand for traditional fuels, such as solids and residual fuel oil, is declining. However, oil products, mainly diesel oil and gasoline, are massively employed in specific uses, mainly for transport. Final demand for natural gas increases by 1.1% per year but slows down in the longer term due to high prices and saturation.

**Figure 27: Baseline Energy and Economy Indicators**

Figure 28 illustrates that energy demand in industry is projected to grow at moderate rates due to considerable reductions in energy intensity related to structural changes towards less energy-intensive manufacturing processes. Relatively high energy demand in the tertiary sector reflects the gradual shift of the European economy towards services. Final energy demand by households is projected to slow down as a result of saturation effects, except for electricity demand which is expected to grow as a result of new specific uses of electricity. The predominant role of the transport sector in final energy demand growth is remarkable. It is only in the long term that the combined effect of transport activity decoupling from economic growth (particularly for passenger transport) and the technological progress of vehicles may lead to a deceleration of energy demand growth in transport. Despite this, transport remains the fastest-growing energy demand sector. This explains the stability of total demand for petroleum products throughout the projection period, except for the period beyond 2030 when oil demand starts to decline smoothly in Europe.

Increasing demand for electricity implies large expansion of power generation capacity, which has to increase by 50% to 2030 compared to today (Figure 29). To meet rising demand and replace ageing plants, total capacity of 825 GW needs to be constructed in the EU-25.
The nuclear electricity sector, under Baseline conditions, faces four main issues: EU requirements to close a number of plants in new member states; end of conventional lifetime of many plants after 2020; nuclear phase-out in three EU countries; likely decisions in large nuclear countries not to replace the entire nuclear fleet after decommissioning. This explains the decline in nuclear capacity, leading by 2030 to a level which is 40% lower than today, despite 48 GW of new nuclear investment. Under Baseline trends, nuclear energy in 2030 is likely to have a share of just 15% in total power generation, down from 30.8% in 2005.

Technological advances, increased competition in the electricity market favouring low capital cost investment, growth of cogeneration to attain a 28% share in 2030 from 16% in 2005, and high growth of mid-load demand explain why, in the medium-term, there is considerable investment in new gas combined cycle plants, despite high gas prices. The baseline scenario projects that 50% of new thermal plants in the coming fifteen years will be gas combined cycle plants. In the longer term, deterioration of gas-to-coal competitiveness drives a considerable shift in favour of investment in new coal and lignite plants. In the 2015 to 2030 period, it is projected that 250 GW of new coal-fired plants will be built, leading to total capacity of solid fuels plants of 300 GW in 2030, up from 190 GW in 2005.

Given that Baseline assumes the continuation of supportive policies for renewables, investment in RES-power plants is found to increase substantially: wind power is projected to reach 190 GW in 2030, of which 47 GW is offshore. Solar photovoltaic is also projected to start rising in the longer term, reaching 10 GW in 2030. Biomass- and waste-burning power plants (including biomass co-firing) are projected to reach a total of 60 GW in 2030. Hydro plants also develop, though at a far lower rate. As a result, electricity generation from renewables is projected to represent 25% of total power generation in 2030, up from 15.7% in 2005.

Because of rising fuel prices and despite technological progress and competition, average electricity prices in Europe are projected under Baseline to increase by 0.2% per year in real terms. Total investment expenditure in power generation is estimated at €1 trillion over the 2005 to 2030 period.

Despite these cost increases, total cost of energy as a percentage of GDP drops slightly over time, from 10.86% in 2005 to 9.57% in 2030.

Under Baseline conditions, carbon dioxide (CO₂) emissions, despite increasing significantly less than GDP and even less than total energy requirements (see Figure 27), remain far higher than the emission reductions targets required to meet Kyoto obligations and climate-friendly post-Kyoto emissions paths. The considerable energy intensity reductions and the significant penetration of renewables projected under Baseline are not enough to curb CO₂ emissions. This is due to three factors that counterbalance the gains from efficiency and renewables: a) energy demand trends for transport are steady and no substitute to oil really emerges under Baseline; b) coal-fired power generation re-emerges in the long run; c) nuclear generation declines and is substituted by coal. The Baseline scenario projects 10.5% higher emissions in the EU-25 in 2030 than in base year (1990) and 3% higher emissions in 2050.
Indigenous production of all energy forms in Europe, except renewables, is projected to decline considerably over time (Figure 30). This trend combined with rising energy needs for oil and gas leads to a serious aggravation of Europe's dependence on energy imports. An analysis of the possible origins of incremental supplies of gas to Europe also shows high dependence on Russian and Middle East gas sources. Total import dependency reaches 68% in 2030, from 50% in 2005, while oil and gas net imports per unit of primary energy requirements grow to 57% in 2030, from 45% in 2005.

Despite the remarkable energy intensity gains obtained under Baseline conditions, the energy future of Europe under current trends and policies is not sustainable in the long run. The persisting high oil needs for transport, the persistently high demand for gas in power supply and in final demand and the declining indigenous energy production in Europe lead to unprecedented long-term import dependency involving high geopolitical risks.

Under these circumstances, energy investors face high uncertainty, because they are exposed to the risk of future climate-related penalties or charges and to the risk of monopoly-driven high price fluctuations or even disruptions in fossil fuel imports. This uncertainty undermines investment, leading to sub-optimal decisions or to postponement of investment. Evidently, this further weakens capacity adequacy in Europe and reduces the potential benefits from technological progress. Without new policies, the European demand and supply energy system cannot deliver the energy restructuring needed to meet long term climate change objectives.

4.3 Alternative Scenarios

Analysis of the Baseline scenario identifies the need for additional policies and measures, especially with respect to the implications of energy import dependence and climate change. For this purpose, alternative scenarios are quantified.

Analysis of Baseline results clearly demonstrates that CO₂-reduction policies are very closely linked to the two other drivers, import dependency and economic competitiveness. With this in mind, we decided to impose on all alternative scenarios, which are quantified through the models, exactly the same ambitious target for mitigating carbon dioxide emissions: under all alternative scenarios the EU-25 is constrained to meet an overall CO₂ emissions cap of -30% in 2030 and -20%
in 2020, compared to 1990. For longer-term analysis, this cap is assumed to become more restrictive: -40% in 2040 and -50% in 2050. This makes the alternative scenarios comparable with each other.

However, the alternative scenarios, as well as a series of other sensitivity analysis scenarios that have also been carried out, adopt different assumptions in terms of the energy policy approach and the technological developments that are needed to meet the emissions cap. In these terms, the alternative scenarios are defined as follows:

- The **Efficiency & RES** scenario assumes that policy focusses on the fields of energy efficiency and renewables. For this purpose, the scenario involves a package of measures promoting energy savings and highly efficient appliances, plus policies facilitating further deployment of renewables, including support for biomass through the Common Agricultural Policy. This scenario does not involve any revision of nuclear policy as compared with baseline and excludes the development of carbon capture and storage (CCS) technology.

- The **Supply** scenario assumes that policy focusses mainly on power generation in order to obtain a low carbon energy system and meet the emissions cap. The scenario does not foresee any additional efforts to promote energy efficiency or renewables over and above the Baseline scenario. This scenario assumes that a new nuclear policy is adopted and put in place, and that CCS is facilitated and successfully developed. The new nuclear policy involves the possibility of extending the lifetime of old nuclear plants (selectively depending on technical constraints), cancellation of planned nuclear phase-out in three member states (but no development of nuclear in ten member states that have had no nuclear energy in the past) and the success of new nuclear fission technology. Regarding CCS, the scenario assumes that CCS-enabled coal- and gas-fired power plants become commercially available and that CO₂ transport and storage develops throughout Europe.

- The **Role of Electricity** scenario does not exclude any means or options towards a low-carbon energy system in Europe. This scenario involves policies promoting energy efficiency on the demand side and policies supportive to renewables as envisaged in the Baseline scenario, but without incorporating any additional policies for renewables or biomass. In addition, this scenario assumes that new demand-side electro-technologies will successfully develop. Some of these technologies improve energy efficiency in specific electrical uses, such as efficient lighting and motor drives, while others facilitate higher penetration of electricity in substitutable energy uses, including heat pumps and plug-in hybrid vehicles. On the supply side, the Role of Electricity scenario mobilises, alongside renewables, both the new nuclear policy and CCS technology, as specified for the Supply scenario.

All alternative scenarios assume that the emissions cap is applied to the EU as a whole and that it will be possible that all sectors and countries of the EU contribute under a perfect allocation scheme to emissions reduction. In other words, all sectors and countries contribute as much as needed to obtain the overall emissions reduction with the condition that all sectors face exactly the same marginal abatement cost. This marginal cost, called “carbon value”, corresponds to the marginal value of the overall emissions cap. The carbon value is a measure of the relative difficulty of meeting the constraint and does not entail any direct cost to consumers or producers, who only bear indirect costs as a result of energy system restructuring.

All alternative scenarios follow the post-Kyoto emissions path (see Figure 31) and involve considerable energy restructuring. Each scenario however enables a different kind of restructuring in order to lead to a low carbon energy system. Through an optimal market equilibrium approach, the model determines the best mix of means and options to reach the constrained emissions path.

The publication on January 10, 2007 of the European Commission's proposal on long-term energy policy, the Strategic Energy Review, manifests Europe's willingness to place a seriously long-term binding constraint on carbon dioxide emissions. The Commission is proposing a series of new policies and targets in the domains of energy efficiency, renewables, nuclear policy, carbon capture and storage in power generation and new technologies in both demand and supply. Although the emissions reductions set out in the scenarios were defined long before publication of the Commission's paper and therefore do not correspond exactly to the targets it proposes, they are nevertheless based on very substantial and increasing reductions in emission levels.
4.4 Discussion of Results of Alternative Scenarios

All scenarios involve reducing final energy demand. In general, the results confirm that policy must give first priority to energy efficiency in order to reduce the carbon intensity of the European economy.

Table 2 shows that Efficiency & RES leads to the lowest level of final energy demand compared to other scenarios. Under this scenario, despite economic growth, final energy demand reaches in 2030 the same level as in 2010 and then even drops by 10% in 2050 from its 2005 level. This corresponds to the main focus of the scenario – improvement in energy efficiency.

Electricity consumption is higher in the Role of Electricity scenario because results show that the success of new electro-technologies, leading to higher use of electricity in cars and thermal uses, also enables cost-effective displacement of emissions from the energy demand side to the supply side. This displacement is such that overall emission-abatement costs are reduced and the level of emissions is reduced overall as well. The advanced electro-technologies lead to energy savings in 2030 of up to 10% in the buildings sector and 7% in industry. The share of electricity in total final energy rises in this scenario against Baseline from 25% in 2030, to 31% in 2030. The share of plug-in hybrid vehicles attains 11% in 2030 and 23% by 2050.

Both the Efficiency & RES and Role of Electricity scenarios show 15% lower energy demand for transport in 2030 than Baseline. This is due equally to a shift in favour of using public transport and to higher efficiency of vehicles. Both scenarios also improve transport’s performance in terms of carbon intensity, through greater use of bio-fuels in the Efficiency & RES scenario (25% in 2050) and greater use of electricity in the Role of Electricity scenario (26% in 2050). Hydrogen and fuel cells start to emerge in both scenarios after 2045.

In the two scenarios involving new nuclear policy, nuclear power generation is around 60% higher in 2030 compared to 2005; it more than doubles in 2050. In all the alternative (non-Baseline) scenarios, electricity from renewable sources increases substantially from 2005. Particularly in the Role of Electricity and Efficiency & RES scenarios, RES-electricity expands in a range between 3 and 4 times higher than its level in 2005.

Renewables achieve their highest share under Efficiency & RES: 45% of all power generation in 2030 and 57% in 2050. This scenario allows renewables to cover 20% of total primary energy requirements in 2030. Compared to the other two
The Role of Electricity scenarios, the additional contribution of renewables is mainly related to the development of biomass.

CCS technology allows considerable avoidance of emissions: under the Supply scenario, over 5 billion tons of CO₂ are stored underground from 2020 to 2030, and 14 billion tons from 2030 to 2050. This may be compared against a total CO₂ storage potential of more than 70 billion tons of CO₂.

Power generation investments work out higher than Baseline in all alternative scenarios. This is related to premature scrapping of some of the older plants. The considerable restructuring of power generation is accompanied by higher average electricity prices, 20% higher in the Supply scenario, 11% higher in the Efficiency and RES scenario and the lowest increase of 9% under the Role of Electricity scenario.

### TABLE 2: SUMMARY OF ENERGY SYSTEM CHANGES (EU-25)

<table>
<thead>
<tr>
<th>Scenario Results for 2030</th>
<th>Baseline</th>
<th>Role of Electricity</th>
<th>Supply Scenario</th>
<th>Efficiency &amp; RES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Energy Demand (2005=100)</td>
<td>118</td>
<td>106</td>
<td>113</td>
<td>102</td>
</tr>
<tr>
<td>Electricity Consumption (2005=100)</td>
<td>145</td>
<td>172</td>
<td>143</td>
<td>127</td>
</tr>
<tr>
<td>Electricity Price (2005=100)</td>
<td>111</td>
<td>121</td>
<td>133</td>
<td>123</td>
</tr>
<tr>
<td>Electricity from Nuclear (TWh)</td>
<td>654</td>
<td>1,643</td>
<td>1,535</td>
<td>852</td>
</tr>
<tr>
<td>Electricity from Renewables (TWh)</td>
<td>1,092</td>
<td>1,359</td>
<td>1,267</td>
<td>1,675</td>
</tr>
<tr>
<td>CO₂ Stored (cumulative Mt)</td>
<td>-</td>
<td>3,797</td>
<td>5,315</td>
<td>-</td>
</tr>
<tr>
<td>Power Investment (cumulative GW)</td>
<td>928</td>
<td>1,090</td>
<td>950</td>
<td>984</td>
</tr>
</tbody>
</table>

All three alternative scenarios transform power generation into a very low-carbon-intensive energy conversion sector: from 0.43 t of CO₂ per MWh in 2000, emissions from the European Power sector decline to 0.15 t/MWh under Efficiency & RES, to 0.13 t/MWh under Role of Electricity and to as low as 0.06 t/MWh under the Supply scenario. In the last scenario, more than 60% of the CO₂ emitted from power generation in 2030 is captured and stored, compared with 42% in Role of Electricity.

The restructuring of the power generation sector is illustrated in Figures 32 and 33 and in Table 3. Gas-fired generation remains important in Efficiency & RES because of lack of other choices, apart from renewables. The Role of Electricity scenario uses all energy forms for power generation in a balanced way. Total generation in this scenario exceeds all other cases because electricity demand is substantially higher. New plants with CCS facilities take a share between 12 and 19% in 2030 and between 17 and 23% in 2050. The extension of the lifetime of older nuclear plants accounts for 78 GW and, by reducing cost, has a downward effect on electricity generation prices.
As mentioned above, the Baseline scenario involves a dramatic increase in Europe's dependence on energy imports. Table 4 shows that the alternative scenarios, as a result of lower energy use and shifts towards carbon-free sources, involve lower energy imports than Baseline.

This is particularly significant for oil: the level of net imports of oil, despite the decline of indigenous oil production in Europe, decreases over time in all alternative scenarios. Oil imports become lower than the 2005 level beyond 2030 in both the Efficiency & RES and Role of Electricity scenarios.

The incremental need (from 2005) for gas imports in the alternative scenarios also decreases against Baseline, but gas imports are generally very inelastic and therefore remain considerable in all alternative scenarios. This of course is due to the fact that emission reduction is the main driver of change.
In terms of incremental gas imports from 2005, the Role of Electricity scenario performs better than the other two scenarios. Incremental imports of coal decrease in all alternative scenarios compared to Baseline, but less so in Role of Electricity because in this scenario electricity generation is highest.

The Role of Electricity scenario thus performs best in absolute terms (Mtoe) of incremental needs for net gas and oil imports from 2005.

In terms of overall dependence on oil and gas imports, in percentage terms, all alternative scenarios reduce dependence versus Baseline. The Role of Electricity exhibits a higher performance than the other two scenarios: dependence on oil and gas imports in percentage terms in 2030 approaches the 2005 level.

All alternative scenarios avoid emissions of carbon dioxide in equal amounts, but each scenario differs in the way it delivers this carbon mitigation. After
applying a breakdown methodology on the model results, one can calculate the net effects of each means of carbon reduction separately for each scenario. This breakdown compares CO₂ emissions in Baseline with those in the alternative scenarios.

**TABLE 4: INCREMENTAL NET IMPORTS OF FOSSIL FUELS (FROM 2005)**

<table>
<thead>
<tr>
<th>MTOE DIFF. FROM 2005</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>185</td>
<td>196</td>
<td>235</td>
</tr>
<tr>
<td>Oil</td>
<td>106</td>
<td>90</td>
<td>68</td>
</tr>
<tr>
<td>Solids</td>
<td>62</td>
<td>128</td>
<td>127</td>
</tr>
<tr>
<td>Efficiency &amp; RES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>188</td>
<td>177</td>
<td>178</td>
</tr>
<tr>
<td>Oil</td>
<td>34</td>
<td>19</td>
<td>192</td>
</tr>
<tr>
<td>Solids</td>
<td>-64</td>
<td>-77</td>
<td>-91</td>
</tr>
<tr>
<td>Supply Scenario</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>203</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>Oil</td>
<td>66</td>
<td>46</td>
<td>134</td>
</tr>
<tr>
<td>Solids</td>
<td>-60</td>
<td>-5</td>
<td>-20</td>
</tr>
<tr>
<td>Role of Electricity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>176</td>
<td>144</td>
<td>145</td>
</tr>
<tr>
<td>Oil</td>
<td>18</td>
<td>37</td>
<td>206</td>
</tr>
<tr>
<td>Solids</td>
<td>-49</td>
<td>34</td>
<td>42</td>
</tr>
</tbody>
</table>

Figure 34 shows the breakdown of overall emissions avoided under Baseline in 2030, on both the energy demand and supply side. The Supply scenario mostly relies on supply-side carbon emissions mitigation, whereas the other two scenarios show a balance between demand and supply actions. The Fuel mix part above takes into account both fuel switching from coal to natural gas and the impact of deterioration of thermal efficiency as a result of the energy needed for carbon capture. However, this last effect is low compared to the overall emissions avoided.

Under Efficiency & RES, power generation mostly relies on renewables and a change of fuel mix in favour of gas to reduce emissions. It also uses more nuclear energy than Baseline: some countries that allow further expansion of nuclear undertake higher investment.

Power generation under the Supply scenario mostly relies on nuclear energy and CCS, and less on renewables. Changes of fossil-fuel mix (i.e., a shift to gas) are lower in...
this scenario, partly because the CCS technology allows use of coal to be maintained and partly because of the higher potential for nuclear development.

The Role of Electricity scenario follows a more balanced approach regarding the relative use of the different means of reducing carbon. The scenario uses not only nuclear and CCS but also renewables in substantially higher amounts in 2030 than Supply and Baseline. This “portfolio” approach, which characterises the Role of Electricity scenario, explains its superior performance in terms of economic cost and carbon value. This balanced approach leads to lower economic costs because it uses every means of reducing carbon at its cost-related optimal level. Excluding an option for carbon-reduction would imply that in order to achieve the same overall amount of CO₂ emissions reductions, some other means will have to be used at non-optimal cost levels.

This is not, however, the only reason why the Role of Electricity scenario performs better in terms of both costs and carbon value. This scenario also maximises the benefits of the portfolio approach because it allows higher cost-effective emissions reduction through greater penetration of efficient electric appliances, electric vehicles, lighting, etc., combined with the transformation of the power sector into a low-carbon energy conversion system. This scenario captures the benefits of advanced electro-technologies (plug-in hybrid vehicles, heat pumps, etc.) for which the Role of Electricity scenario assumes a significant degree of market-acceptance and technological success. The role of these electro-technologies justifies the term “intelligent use of electricity” as they promote energy efficiency in specific electricity uses combined with higher use of electricity in thermal and transport uses.

**Figure 35: Demand for electricity (EU-25)**

| TABLE 5: Cost implications |

<table>
<thead>
<tr>
<th>Results for EU - 2030</th>
<th>Baseline</th>
<th>Role of Electricity</th>
<th>Supply Scenario</th>
<th>Efficiency &amp; RES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost of Energy (2005=100)</td>
<td>146</td>
<td>147</td>
<td>161</td>
<td>156</td>
</tr>
<tr>
<td>Total Cost of Energy as % of GDP</td>
<td>9.57</td>
<td>9.64</td>
<td>10.61</td>
<td>10.27</td>
</tr>
<tr>
<td>Total Unit Cost of Energy (2005=100)</td>
<td>124</td>
<td>139</td>
<td>142</td>
<td>153</td>
</tr>
<tr>
<td>Average Price of Electricity (2005=100)</td>
<td>111</td>
<td>121</td>
<td>133</td>
<td>123</td>
</tr>
<tr>
<td>Carbon Value (€’2005/tCO₂)</td>
<td>5</td>
<td>35</td>
<td>63</td>
<td>125</td>
</tr>
<tr>
<td>Power Investment in billion € (up to 2030)</td>
<td>933</td>
<td>1,115</td>
<td>1,036</td>
<td>1,039</td>
</tr>
</tbody>
</table>

7 The indirect use of renewables through heat pumps (the energy extracted from the environment) is not included in the calculation and therefore the indirect impact of the Role of Electricity scenario on renewables is not represented. Recent papers from the European Commission have recognised the use of heat pumps as a renewable source of energy, but a standard statistical system on heat pumps and renewables has not yet been established by Eurostat.
The cost implications of emissions mitigation under the different scenarios show the advantage of the Role of Electricity scenario resulting from the supply “portfolio” approach combined with the “intelligent” use of electricity on the demand side (Table 5).

The additional costs incurred under the Role of Electricity scenario are reasonable: the total cost of energy as a percentage of GDP increases slightly from Baseline, while the other two scenarios involve a significant increase in this percentage.

The Role of Electricity scenario holds greater promise for economic development in view of its lower energy costs and is also more robust because its reliance on a broader portfolio of supply- and demand-solutions allows the system to better absorb unexpected changes or developments.

It is important to underline that all three alternative scenarios replace the transfer of funds abroad to pay for imported energy with higher investments and other costs that are paid to domestic European sectors, such as the equipment goods industry. This substitution has positive effects on economic growth. However, all three scenarios imply higher expenses in the energy sector than for the rest of the economy. Since energy is a “material” production sector, it usually has a lower multiplier effect than other sectors, which impacts negatively on economic growth. The Role of Electricity scenario substitutes more imported energy than other scenarios and at the same time entails lower costs for the rest of the economy. Therefore, this scenario has an overall higher performance in terms of economic growth implications. However, the net long-term effect on economic growth will depend on the technological and industrial dynamics of Europe: energy and environmental restructuring under certain conditions of economic and industrial policy may well trigger “endogenous” economic growth, employment and exports of equipment goods and services. In summary, it has to be underlined that energy restructuring, despite the high cost, could lead to equal or even higher GDP growth.

<table>
<thead>
<tr>
<th>TABLE 6: OVERALL PERFORMANCE OF ALTERNATIVE SCENARIOS</th>
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<tbody>
<tr>
<td><strong>Total Cost of Energy</strong></td>
</tr>
<tr>
<td>2005 = 100</td>
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<tr>
<td>Baseline</td>
</tr>
<tr>
<td>Role of Electricity</td>
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<tr>
<td>Supply Scenario</td>
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<td>Efficiency &amp; RES</td>
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(Results for 2030 and 2050 expressed as an index, with 2005 = 100)9

4.5 Concluding Remarks on the Modelling Work

The Baseline scenario clearly represents a non-sustainable future in terms of environmental impact (climate change) and security of supply (import dependence).

The Baseline scenario could improve if the nuclear option was unlocked (ie no phase-out and extension of lifetime) and if energy efficiency and renewables policies were to prove more effective.

Under an ambitious CO₂ emissions-reduction target of -30% in 2030 versus 1990 levels, an electricity-related package of low-carbon solutions on both the demand and supply sides can be extremely cost-effective.

---

8 The energy models do not capture this because economic growth is an external constant assumption.
9 CO₂ emissions were roughly the same in 2005 as in 1990.
10 The ratio “Dependence on Imported Oil and Gas” represents the degree of dependence of the European energy system on sensitive imports and is calculated by dividing net imports of oil and gas by total primary energy requirements.
The role of electricity delivers considerable benefits by reducing import dependence on oil and gas. The package enables high technological progress in all electricity domains and can induce positive economic growth effects. The package does imply an additional cost to consumers, but this is reasonable and optimised.

In this package, higher but intelligent use of electricity on the demand side is combined with very low-carbon power generation: this is the key to cost-effectiveness. This is made possible by the success of a series of technologies and policies, such as:

- Plug-in hybrid vehicles
- Heat pumps, efficient lighting etc.
- Ambitious development of energy efficiency
- Higher potential of renewables
- Carbon capture and storage
- Nuclear energy

The cost-effectiveness of the electricity-related package relies on its balanced “portfolio” approach and on the intelligent use of electricity. All options, for both demand and supply, must be kept open so as to exploit their highest cost-effective potential. Approaches that exclude certain options are not cost-effective.

The sensitivity analyses, the long-run (up to 2050) projections and also scenarios that assume very high fossil-fuel prices confirm the above results and demonstrate their robustness.
5 Policy Recommendations
A positive message:

The analysis described in this report shows that electricity has the potential to contribute substantially to the three main pillars of European energy policy. It holds the key to substantial reductions in greenhouse gas emissions at reasonable cost to the economy, while at the same time helping to reduce oil and gas dependency.

In order to seize this opportunity, a clear energy policy pathway must be implemented without delay. This new path energy policy for the coming decades must be based on five equally important keystones, which must be pro-actively developed in parallel.

- **Unleash the potential of energy efficiency**
  An energy savings culture must be encouraged among all elements of society, using a variety of tools. Education, incentives, standards and labelling, research and technological development – each one must contribute to fostering energy-efficiency in all sectors of the economy: in households, in industry and service sectors, in transport and through all energy vectors and technologies.

- **Develop a low-carbon electricity system by using all available options**
  The next decades must see further progress towards a low-CO₂ electricity generation mix through the pro-active use and development of all available options: hydropower, other renewable energy sources, nuclear energy, and clean fossil-fuel technology including carbon capture and storage. Any policy that tends to exclude specific elements of this balanced portfolio will fail to build a robust and economically-sound low-carbon electricity system.

- **Intelligent electrification of the economy**
  Intelligent electrification of the economy entails two vital imperatives.
  The first is to improve electricity efficiency on both the supply and demand side by developing more efficient power generation technologies and by improving efficiency in all kinds of applications including lighting, standby power, motor drives, etc.
  The second is to actively develop the far-reaching synergy between CO₂-low electricity supply and energy-efficient demand-side electro-technologies.
  This process must be accelerated in many industrial or commercial applications and public transport and must be pro-actively extended to two sectors where electrification allows very substantial progress in terms of energy-efficiency, CO₂-emissions reduction, and oil/gas dependency: heating and cooling through the use of heat pumps; and road transport via plug-in hybrid cars.

- **Consistent deployment and a market-oriented approach**
  The benefits of both existing and new technologies, on both the demand and supply side, must be exploited through practical take-up. This calls for a consistent deployment strategy oriented both to making widespread use of existing technologies, and to making new technologies a business reality through R&D, demonstration programmes, long-term CO₂ price signals and removing barriers to market integration.
  Public support policies, where these prove to be necessary, should be organised in such a way as to promote cost-efficiency and to foster speedy integration of new technologies into the market.
  The long-term nature of supply-side and of certain demand-side energy investments requires long-term visibility for carbon pricing so as to facilitate the integration of climate change action into investments and business strategies.

- **Global cooperation on global issues**
  The new path energy policy reinforces supply security and fosters a worldwide approach to climate change through diversification of energy supplies, international solidarity mechanisms, partnerships between suppliers and users of energy at international level and in the business domain, international cooperation on R&D and demonstration projects, and an international framework for climate change policies and cooperation.
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The Role of Electricity

A New Path to Secure, Competitive Energy in a Carbon-Constrained World

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