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Low Carbon Electricity Systems

Electricity in the next decade

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1 INTRODUCTION

This document is the overall report of the seminar “Electricty in the next decade”, the first seminar in an annual series of events regarding “Low carbon electricity systems”. KEMA, ECI and Leonardo ENERGY are jointly organizing these events.

Next to the topics presented during the first event a few additional topics have been added in order to create a white paper and a more complete picture on the theme “Electricity in the next decade”.

1.1 Background

The global demand for (electrical) energy is growing at a rapid pace, while restrictions on traditional electrical power generation from fossil fuels are tightening as global fossil fuel resources diminish. The transition towards sustainable power generation, using a significant amount of renewable energy resources, is already in full swing, but the implications for the electrical system infrastructure and services have not been fully explored yet. It is expected that within the next decade a paradigm shift in the electrical system will occur, harnessing multiple forms of renewable energy, mostly distributed in nature, simultaneously and storing, transporting and controlling it via intelligent electrical infrastructure, also known as Smartgrids. The maturity of each technology will ultimately determine its contribution.

KEMA, Leonardo ENERGY and the European Copper Institute have been working together on a wide range of energy related topics for several years in a row. They decided to create a forum for the exchange of practical knowledge among experts in a series of annual seminars called Low Carbon Electricity Systems. The aim is to identify actions to accelerate a move towards low carbon electricity. The theme of the 2009 edition is “Electricity in the next Decade”. Main two questions to be answered are: What action should be taken to accelerate the move towards low carbon electricity? What are the options for policy makers and market players?

1.2 Objectives

This report briefly captures the technologies involved as well as the views and findings of those specialists active in the sustainable energy field that were present at the aforementioned event regarding the evolution of the electricity systems in the next decade (up to an horizon of 2020). Furthermore, it is complemented with promising technologies and its prospectives that were not directly discussed at the event.

Three stages of the electrical energy supply chain has been identified and the technology and future perspectives enabling a low carbon electrical system discussed accordingly.
The three stages are:

1. *Low carbon electricity generation*. Covering generation from renewable energy sources and low carbon fossil fuel alternatives.
2. *Low carbon electricity networks*. Covering, electrical transmission and distribution through future electrical networks, or smartgrids, and the quality of supply.
3. *Low carbon electricity services*. Covering ancillary services provided for grid operators as well as for end-users when implementing storage or electrical transport, for example.

The following issues are addressed for each topic mentioned, as far as they are applicable:

- state-of-art of the technology
- impact/Potential on electricity generation and infrastructure
- challenges faced
- additional benefits regarding low carbon society, if applicable.

It is the objective of this report to provide an objective, scientific view on the electricity system of the next decade, with the state-of-the art information currently available. It is not intended as a complete and comprehensive reference or as a road-map.

2 LOW-CARBON ELECTRICITY GENERATION

Low carbon electricity generation focuses on renewable energy resources such as wind, solar - PhotoVoltaic (PV) and Concentrating Solar Power (CSP) – hydroelectric power but also new technologies are emerging/maturing such as ocean energy, combined heat power (CHP) and fuel cells.

At least one example of each of the above mentioned renewable energy resources is discussed in this section, with the appropriate renewable energy source indicated in the respective paragraph heading itself.

2.1 WIND: Large-scale wind generation[21]

Electrical energy is generated from wind by means of wind-forced mechanical rotation of electrical generators using wind turbines. Wind turbines range from a few kWs, often referred to as micro-generation for domestic application, to tens of MWs, as implemented in large wind farms.

The potential for wind as a renewable resource in the world is considerable. Moreover, wherever the wind exceeds approximately 6 m/s there are possibilities for exploiting it economically, depending on the costs of competing power sources[9]. This potential is not limited to land-based wind turbines as significant possibilities exist of installing large wind farms in shallow waters around the coasts or further off-shore.

2.1.1 State of the art

Wind energy is one of the fastest growing energy technologies, with an average global growth over the last several years of more than 30% annually. At the end of 2008 global installed capacity stood at over 121,000 MW. Around 54% of the globally installed capacity (65,000 MW) is located in EU countries, with Germany alone accounting for 27.8% of the global installed capacity. Spain, the USA, India and Denmark follow[9],[17]. Total production in 2008 amounted to 142 TWh, according to EWEA[17].

2.1.2 Impact/Potential on electricity generation and infrastructure

It is expected that power generated from wind energy will contribute significantly to the electricity supply of Europe in the next decade and even beyond. It is anticipated that more than 300GW of installed power, of which 120GW off-shore, will be installed throughout Europe in the year 2030, producing 935TWh, of which 469TWh off-shore[17].

2.1.3 Challenges faced

This amount of wind power requires much more flexibility in the energy system, both in a technical as in an energy market manner.

In this regard, nine companies joined forces in executing the *TradeWind* project, the first EU-level study to come up with recommendations for a better European grid and an improved power market design to accommodate the integration of large amounts of wind power.

Increasing the grid capacity is a number one priority as the increase of electricity demand as well as the ageing grid already requires extension and reinforcement of the grid. Furthermore, with the introduction of more wind power into the electrical grid, the reserve capacity has to step up with +10% with a share of 15% wind power.
Spreading wind farms throughout Europe and applying shorter forecasting periods (e.g. reduce gate-closure time) to predict the energy output, improves the economic integration of wind power and makes the additional percentage reserve capacity go down. The additional costs of this reserve capacity, however, is relatively small compared to the investment costs of wind power, i.e. about € 0,5 to € 4,0 per MWh.

Regardless of the amount of conventional generation capacity displaced by wind, sufficient conventional backup capacity has to be retained to ensure both the security of supply and of energy supply. With higher penetrations of wind in the system, extra capacity may be needed to supplement the retained backup capacity.

It is recommended to have a closer look at energy storage (see also Section 4.1) as a potential enabler of wind power integration as alternative to more backup capacity.

2.1.4 **Additional benefits regarding low carbon society**

As wind is delivered free of charge the operational costs of energy dramatically reduces with increasing wind power. The costs savings has been calculated to be almost € 500 million per annum[10]. This could be invested in grid extensions and interconnectors amongst others.

Figure 1 Impression of transnational off-shore HVDC grid interconnecting various EU countries

A transnational offshore HVDC grid, see Figure 1, can be attractive to transport (wind) power over large distances and create synchronous energy market zones. This, however, will require quite some coordination between countries and institutions and money.

2.2 SOLAR: Large-scale concentrated solar generation[22]

Concentrating Solar Power (CSP), also referred to as solar thermal electric power, is the generation of electrical power from the heat generated by solar radiation (thermal energy), e.g. via heat exchangers and steam turbines.

This technology comprises five basic sub-systems:
- collector
- receiver
- transport
- storage, and
- power conversion.

The collector captures and concentrates solar radiation, which is then delivered to the receiver.
The receiver absorbs the concentrated sunlight, transferring is heat energy to a working fluid via a transfer system (usually a mineral oil, or more rarely, molten salts or metals, steam or air).
The transport-storage system passes the fluid from the receiver to the power-conversion system, usually a steam turbine.

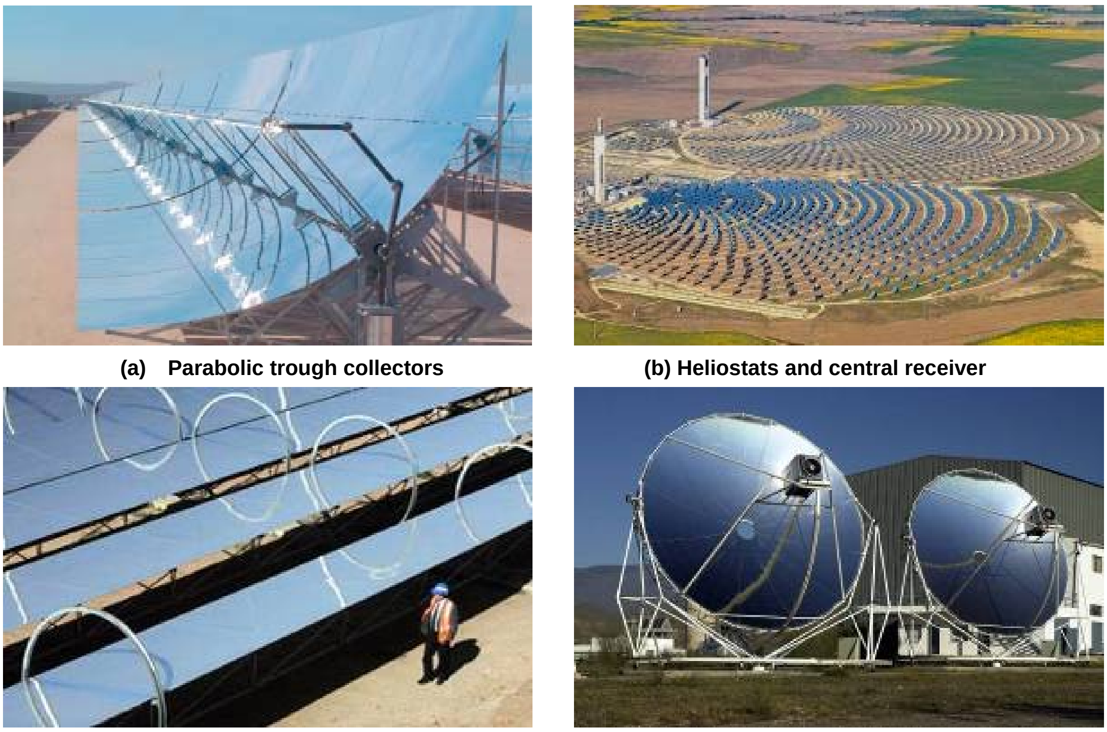
Solar energy can either be converted directly into electricity or stored as sensible heat for subsequent delivery to the power conversion system. Storage de-couples the collection of solar energy from its conversion to electricity and makes operation in the evening or during cloudy weather possible, thus it becomes dispatchable (see also Section 4.1).

Some designs also include a secondary fossil fuel driven heat source that can either charge the storage system or drive the power-conversion system during periods of low sunlight. In addition to producing electricity, solar-thermal technologies can produce hot water and steam for industrial applications.

2.2.1 State of the art

Four major solar-thermal technologies can be identified, these are:

- *Parabolic trough system*, which concentrates solar energy onto a receiver pipe located along the focal line of a trough collector (one axis tracking), see Figure 2(a).
- *Central receiver system*, which uses sun tracking mirrors, called heliostats to reflect solar energy onto a receiver/heat exchanger located on top of a tower, see Figure 2(b).
- *Linear fresnel reflectors*, which concentrates solar energy onto a stationary receiver pipe located along the focal line of a series of essentially flat mirrors (one axis tracking) , see Figure 2(c).
- *Parabolic dish system*, which uses a two axis tracking dish reflector to concentrate sunlight onto either a receiver/engine or a receiver/heat exchanger mounted at the focal point of the dish, see Figure 2(d).



(a) Parabolic trough collectors

(b) Heliostats and central receiver

(c) Linear fresnel reflectors

(d) Parabolic dishes with stirling motors

Figure 2 Main CSP concepts for large and small scale generation

CSP plants function similar to centralised conventional power plants in terms of grid integration as there is first, second and third level control of a CSP plant. This eases the integration of such large-scale plants into the grid.

CSP plants using parabolic troughs are already a reliable and demonstrated technology. Several plants, with an overall installed power close to 2000 MW, are either in construction or in operation, mainly in Spain and the USA. Parabolic through collectors and heliostat fields are in operation since the early 80´s with proven performances.

CSP plants are dispatchable and their dispatchability can be enhanced by new storage technologies and/or hybrid concepts using other renewable or conventional fuels. This feature, together with a good forecast ability for solar radiation, addresses the most important drawback of renewables, being that they are in general variable, non predictable and non dispatchable.

2.2.2 **Impact/Potential on electricity generation and infrastructure**

In the next decade a significant deployment of CSP technology can be expected, specifically in the sunniest parts of the globe. The projects currently under construction and others in the pipeline aim to reach 15,000 MW in the year 2014. Afterwards, technology maturity and market deployment will most likely bring prices down, paving the way for large-scale deployment.

A huge development of CSP is currently taking place in Spain, but also significant activity is documented in the US and increasing activity in the Middle East and North Africa, see also the DESERTEC program[2]. The latter regions have the advantage of a significantly higher radiation and a lower cost for land, which provides ample opportunities for cooperation with Europe. A reasonably growth of up to 60GW-170TWh can be expected up to the year 2030.

2.2.3 **Challenges faced**

The main challenge to be faced is cost. Innovation in systems, components as well as manufacturing technology will prove to be essential for this technology to succeed.

As far as system efficiency is concerned there is still room for improvement, mainly through higher working temperatures and better receiver performances.

Up to now the implemented CSP plant size has been limited by regulatory or financial reasons, however the optimal plant size is calculated to be bigger than the current applications. This creates challenges by itself but also for the required storage performance, in terms of capacity, operating temperature and cost.

A reduction in operating and maintenance cost of such plants is foreseen throughout the next decade as in-depth knowledge of these plants will become available allowing optimisation of the cost structure to take place.

Another issue to be addressed is the availability and use of water within the CSP plant. Unfortunately, the locations with the best irradiation on the globe and therefore the most suitable for placing a CSP plant, inherently is also the location with the least amount of available water.
Again, innovation will be required to design efficient CSP systems using as little as possible water.

2.2.4 **Additional benefits regarding low carbon society**

Additional benefits from a CSP plant include water desalination or cooling, which might bring important benefits in some specific places.

Despite being at the beginning of the learning curve, CSP already offers high value electricity generation pattern in terms of storage ability, dispatchability, ancillary services and possibility to be hybridized with biomass or fossil fuels.

2.3 SOLAR: Photovoltaic solar generation

Photovoltaic cells convert the sun's energy directly into direct current (DC) electricity. A particular advantage of this technology is that it can be very effectively integrated into the structure of buildings, see Figure 3.

Figure 3 Example of PV integrated in facade of an office building(Würth Solar)[1]

A PV system consists of a module (array of cells generating the electricity) and a balance-of-system (BOS) including (if applicable) the cabling, battery, charge controller, dc/ac inverter and other components and support.

From a distribution system perspective it is important to note that this technology requires its DC output to be converted to AC at the interface with the grid. This process introduces harmonic distortion to the grid and it is vital that the level of this distortion is controlled within limits set by industry standards (See also Section 3.2 for more on quality of supply).

2.3.1 State of the art

In recent years the most of the growth in PV has been driven by grid-connected applications, however the relative proportion of grid to off-grid PV varies from country to country depending on local conditions and government incentives. Some large grid-connected plants have been produced around the world – notably in Germany, Italy, Switzerland, Spain and the USA.

In 2008, the Global Photovoltaic (PV) market reached 5.6 GW and the cumulative PV power installed totalled almost 15 GW[18] compared to 9 GW in 2007, see also Figure 4. Spain represented almost half of the new installations in 2008 with about 2.5 GW of new capacities, followed by Germany with 1.5 GW of additional connected. The US confirmed its trend with 342 MW of newly-installed PV systems, followed by South Korea which registered 274 MW of PV installations over the year. Italy connected almost 260 MW while France, Portugal, Belgium and the Czech Republic made good scores confirming Europe's Global leadership in the deployment of solar PV energy.

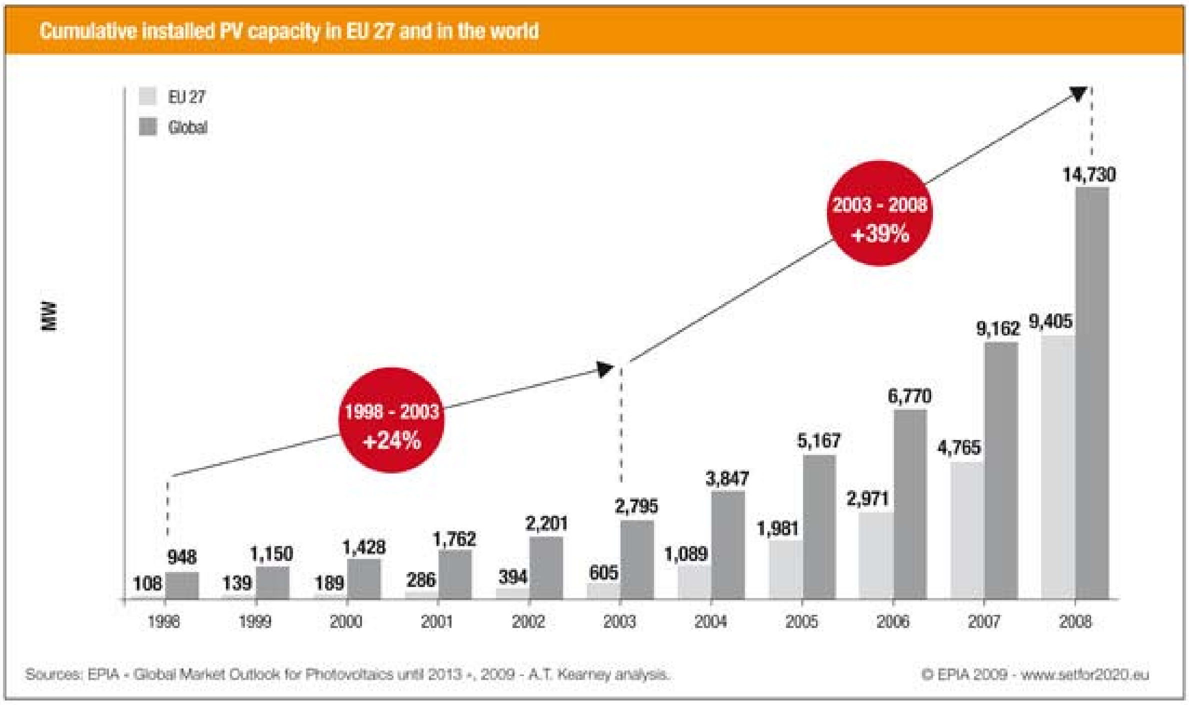


Figure 4 Total cumulative PV installed power (MW) by the end of 2008[18].

Wafer-based crystalline silicon is the dominant technology, owning more than 95% of the market share, because it is widely available, it has proven reliability and it is well understood as it is founded on the knowledge and technology originally developed for the electronics industry.

The market share of thin films, which include thin-film silicon, copperindium/gallium-selenide/sulphide (CIGS), amorphous silicon (a-Si) and cadmium telluride (CdTe), has remained at very modest levels over the past decades and reduced from 15% in 1995 to 5% today. Thin films have the important potential to extend the PV learning curve beyond the point that may be reached by crystalline silicon technology, CIGS, as an emerging technology, could compete with wafer-based crystalline silicon but for their development, scaling up of manufacturing is necessary.

The contribution of PV power generation on the overall electricity production is still low (<<1%). The improvements being researched are mainly focussed on cost reduction and integration into the built environment.

The price of standard PV modules is currently approximately 3 €/W. This could be reduced to 2 €/W by 2010, 1 €/watt-peak in 2020 and 0.5 €/W in 2030. After 2030 a further price reduction is expected, see Figure 5.

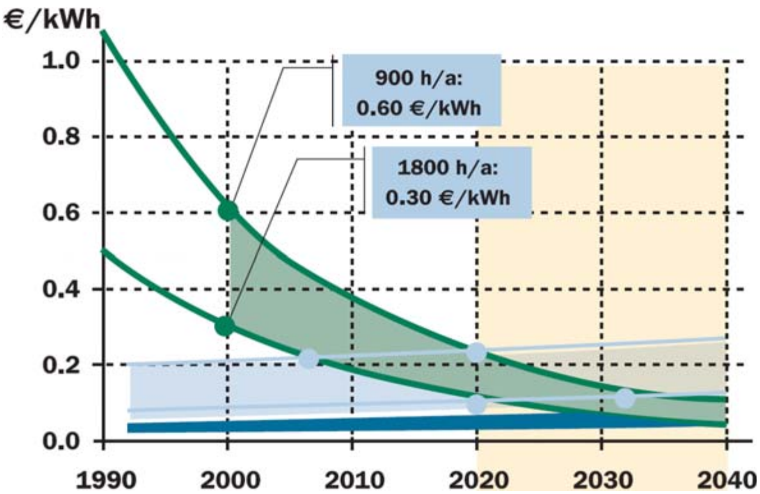


Figure 5 Generation costs of PV electricity[3]

The average usable lifetime of a PV-panel is approximately 20 years, with that of its associated grid inverter being only 10 years. The costs are relatively high, approximately 300-600 €/MWh thereby approaching current retail prices for electricity.

2.3.2 **Impact/Potential on electricity generation and infrastructure**

The photovoltaic (PV) market remains one of the most dynamic sectors globally. Global annual growth rates of over 35 % were experienced over recent years. Even with the temporary shortage of silicon in 2006, more systems were installed than in the previous years.

The global PV market is currently dominated by China, Germany, USA and Japan. China will probably balloon its agenda for installed solar photovoltaic (PV) power capacity to 2 GW by 2011 and 10 GW by 2020 under its stimulus plan for renewable energy, according to 'World of Photovoltaics'[4].

Already, new markets with promising potential are emerging. Italy, Spain, Greece and France are some of the countries which will fuel the growth of the PV sector. Over the last decade the PV sector has become an important industry in many countries. Increasing employment and industrial growth are key indicators when looking at the PV industry.

With adequate support mechanisms (feed in tariffs) a global annual market of 20 GW_{peak} could be reached by 2010, see also Figure 4. PV system prices will decrease by at least 5 % annually over the next two decades. This will further foster the attractiveness of solar power and support market growth. Cost decreases will also ensure that PV becomes competitive with peak and consumer electricity prices in the next decade[16].

It is anticipated that the PV market reaches 22 GW by 2013 under a policy-driven scenario which would mean a compound annual growth rate (CAGR) of 32% over the period 2008-2013. For a more moderate growth scenario, the annual market is expected to range just above 12 GW with a CAGR of 17% over the period 2008-2013[18].

These estimates are consistent with the Japanese Government's objective of 50-200 GW. They are still far below the estimated technical potential, and therefore, it is expected that PV could grow much larger in the decades beyond 2030.

China's solar PV installed capacity is likely to reach 10,000-20,000 megawatts by 2020, with the implementation of its solar photovoltaic (PV) roof plan and other supportive measures, such as a plan to build the country's largest solar PV project in Dunhuang, Gansu, with a primary installed capacity set at 10 MW.

2.3.3 **Challenges faced**

Besides the evident issue of high cost, several other barriers exist which hinder the large scale deployment of PV. These include technical issues, manufacturing issues, the structure of the electricity sector, standardisation, financing, education and training of installers and market awareness/public acceptance. The different barriers need to be systematically clarified and addressed, with the involvement of all stakeholders, including those outside the PV community.

The capability of PV to be utilised in certain applications under current economic and technical conditions depends on the geographical location and the climatic zones, as well as cost. PV generators are generally a good solution for basic needs in rural applications to improve living standards. To solve the problems associated with intermittency and dispersion, hybrid solutions can be implemented combining the use of the full range of renewables, solar, hydropower, wind in coastal areas, and biomass. Lower cost and increased performance PV will ensure that uptake in all markets is increased in the future.

2.3.4 **Additional benefits regarding low carbon society**

The advantages of PV include:
- complementarity with other energy sources, both traditional and renewable
- flexibility in terms of implementation. PV systems can be integrated into consumer goods or into buildings, installed as separate mobile or non-mobile modules, or in central electricity generating stations
- production of electricity without greenhouse gas emissions.

The large-scale dissemination of PV for rural use in developing countries will have provided access to electricity to more than 100 million families by 2030, thus positively affecting the lives of half a billion people (out of the 1.7 billion people who do not have such an access today).

2.4 WATER: Hydroelectric power generation

Hydro-electric power generation envolves the conversion of energy from a supply of water deposited at a suitable head by the action of the cycle of evaporation and rainfall produced by the effect of solar radiation. An essential requirement is, therefore, that the water should be at a suitable height above a lower reference point to where the water could flow and be discharged. The difference in levels between the water and discharge point represents the potential energy that would become available for use should water be allowed to flow between the two levels, see also Figure 6

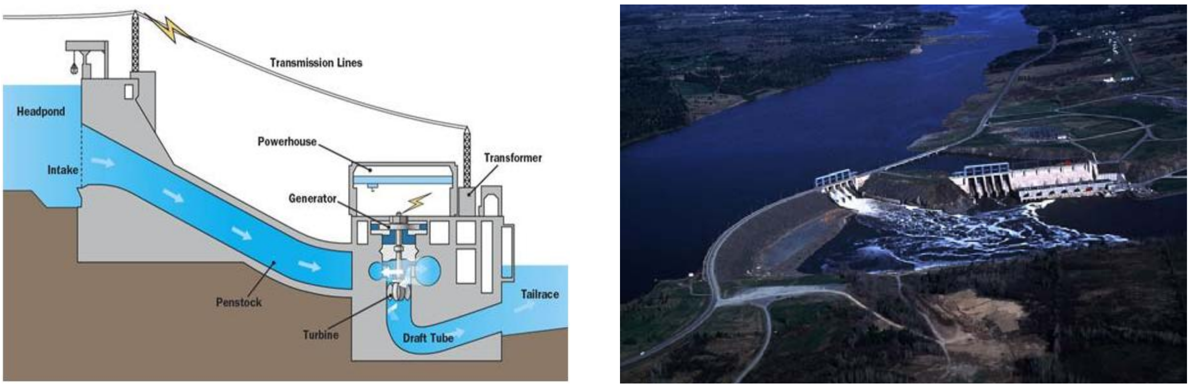


Figure 6 Hydro-electric power generation, principle (left) and Mactaquac hydroelectric dam (right) [5]

2.4.1 State of the art

Hydropower is by far the most significant renewable resource of energy exploited to date. According to the international energy agency's (IEA's) "World Energy Outlook 2006", hydropower output worldwide is projected to increase from 2,809 TWh in 2004 to 4,749 TWh by 2030, representing an increase of 2% year to year on average. Against a projected growth in global electricity generation of 2.6% on average to 2030 practically doubling from 17,408 TWh in 2004 to 33,750 TWh, the share of other non-hydro renewable sources in total electricity generation is predicted to increase from 2% now to almost 7% by 2030. This anticipated increase in the use of other renewable resources occurs largely in OECD countries.

2.4.2 Impact/Potential on electricity generation and infrastructure

In 2001 hydropower was the world's second largest source of electricity. Now it ranks fourth behind coal (40% now, increasing to 44% in 2030), gas (20% now, increasing to 23% by 2030) and nuclear (16% in 2004, but dropping to 10% in 2030). According to the IEA, with the growth of conventional generation, the share of hydropower in electricity production will fall from 16% to 14%, yet only about 31% of the economic potential worldwide had been exploited by 2004. In the OECD countries the best sites have already been exploited and environmental regulations constrain new development. In developing countries many large hydropower projects have been adversely affected by concerns over environmental and social effects of building large dams. The rapidly expanding demand for electricity, the need to reduce poverty and to diversify the electricity mix, however, are leading several countries to focus again on this domestic source of electricity where the economic potential is still very large.

2.4.3 Challenges faced

As with most renewable energy projects the costs per kWh of output from hydroelectric stations have historically been higher than for conventional coal/gas or oil-fired stations. This is entirely due to the initial capital costs of the extensive civil engineering works involved and to the very long periods of construction, during which costs are incurred and interest on financial investments (loans) has to be paid, without receipt of any compensating income. In contrast, operating costs are very low because there are no fuel costs and the additional fixed costs of running the plant are comparable with a thermal power station.

Because a very large portion of the lifetime costs is incurred before a scheme is operational, the cost of borrowing is one of the major parameters to be considered when assessing the viability of any scheme. As a result, the construction of many hydropower schemes can only be justified by incorporating them within larger schemes producing additional benefits such as irrigation, flood control or navigation.

2.4.4 Additional benefits regarding low carbon society

Water can be stored above the dam feeding the hydro-electric plant ready to cope with peaks in demand.

Hydro-electric power stations can increase to full power very quickly, i.e. is dispatchable.

Electricity can be generated constantly.

Hydroelectric power stations can be set up in almost any size, depending upon the river or stream used to operate them; big enough to power a single home, factory, small town, or large city.

2.5 WATER: Ocean power generation[23]

The generation of electricity from ocean energy is performed via the following main emerging ocean power technologies. All of these technologies do have the potential to make a valuable contribution to the world's energy needs in the long term.

Wave energy: The energy captured in the movement of ocean waves can be converted into electricity via:

- Heaving devices, devices that convert the vertical motion of a buoy when travelling on a wave into electricity, see Figure 7(a)
- Oscillating water columns, devices that by wave movement force air from an enclosed chamber through an electrical generator, see Figure 7(b)
- Pitching devices, devices that convert the relative vertical motion of a segmented floating body when travelling on a wave into electricity, see Figure 7(c)

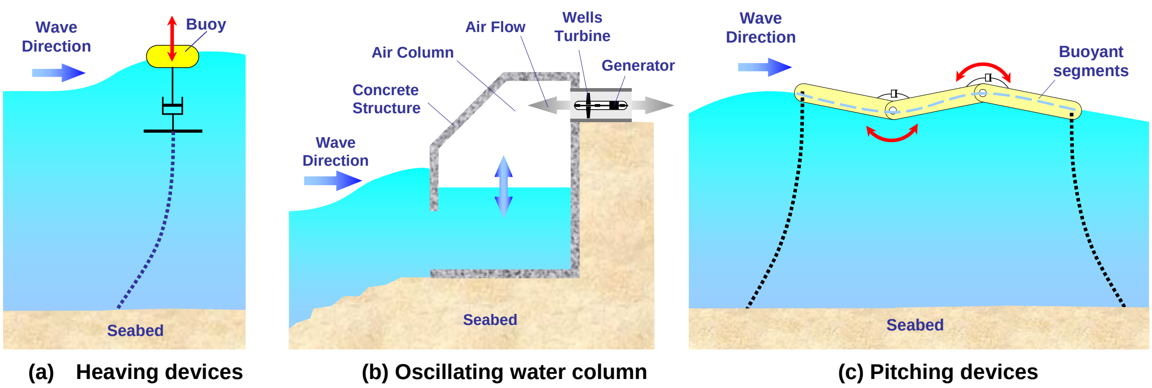


Figure 7 Main wave energy concepts

Tidal energy: The head created by tides can be converted into electricity by placing an electrical generator between the sea and an estuary, see Figure 8.

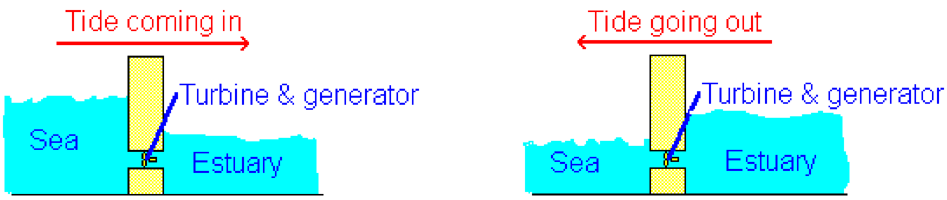


Figure 8 Tidal energy conversion concept

Salinity gradient energy: Electricity can be generated by using the voltage difference created when sweet and salt water mix, via an osmotic membrane, see Figure 9.

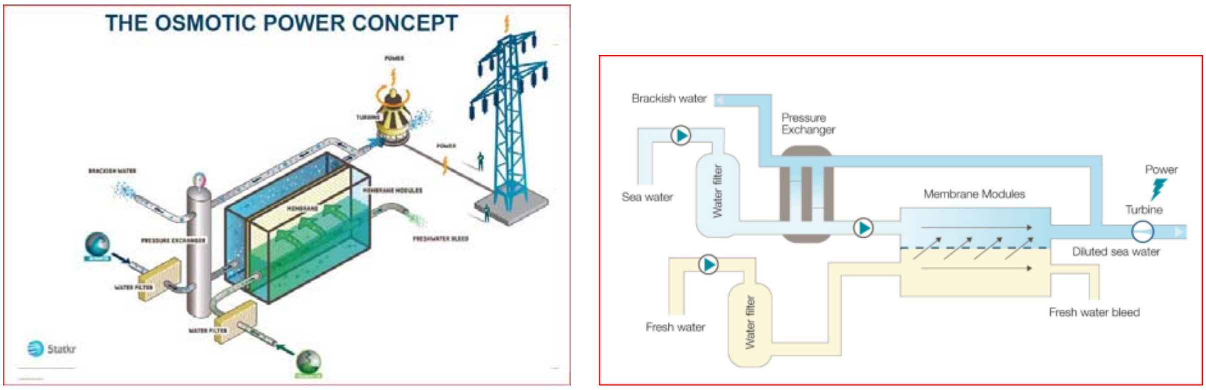


Figure 9 Salinity gradient power generation concept

Ocean thermal energy conversion (OTEC): OTEC is an energy technology that converts solar radiation to electric power. OTEC systems use the ocean's natural thermal gradient—the fact that the ocean's layers of water have different temperatures—to drive a power-producing cycle. As long as the temperature between the warm surface water and the cold deep water differs by about 20°C, an OTEC system can produce a significant amount of power, see Figure 10.

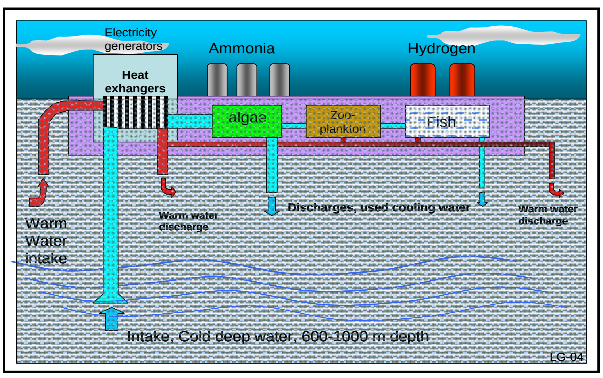


Figure 10 Ocean thermal energy conversion concept

The theoretical global resource is estimated to be in the order of:
- 8,000 - 80,000 TWh/year for wave energy;
- 800 TWh/year for tidal current energy;
- 2,000 TWh/year for salinity gradient energy;
- 10,000 TWh/year for ocean thermal energy.

2.5.1 State of the art

The ocean energy sector has matured significantly over the last 5 years, and is entering the stage of early commercialization. 2020 might be too early for Ocean Energy to make a significant contribution, but if it receives adequate support, it can reach an installed capacity of 30 to 40 GW around 2025.

The current situation of the technology development and (large-scale) implementation per conversion concept is as follows:
- Wave energy (grid connected):
  - 0.4 MW and 0.5 MW OWC of the coast Pico and Islay by 2000
  - 2.25 MW Pelamis of the coast Portugal by 2008
  - 0.5 MW section Wave Star Energy of the Danish Coast by 2009
  - 7 MW Wave Dragon of the coast Wales by 2010 -2011
- Tidal:
  - Barriers: 240 MW France at 1966 and 20 MW Canada
  - Current: 1.2 MW MCT of North Ireland by 2009, 1 MW France 2010
- Ocean Salinity:
  - 1-2 MW Norway 2010-2012
- Ocean Thermal:
  - 0.2 MW Hawaii 1993 -1998.

2.5.2 Impact/Potential on electricity generation and infrastructure

All of these technologies do have the potential to make a valuable contribution to the world's energy needs in the long term. However, the technology is currently only at the edge of a market breakthrough.

The potential for wave energy conversion is large, mainly due to fact that:
- waves are easy to forecast for periods exceeding eight hours for up to six days in advance

- sea states are very stable
- wave energy delivers high energy densities
- systems are easily integrated into the electrical grid.

It has been predicted that wave energy will have 30-40 GW installed by the year 2025, approximately the same as was the situation for wind in the year 2005.

2.5.3 Challenges faced

In search for suitable locations

The earth's sea surface is huge, but that does not imply that the potential locations for harvesting ocean energy are endless. In certain regions such as the North Sea, conflicts of interest might grow between ocean power and shipping routes, fishing grounds, off-shore wind parks, and drilling platforms. Paradoxically, the sea could become a crowded place.

For ocean power installations that are located far from the coastline, transporting the electricity to the mainland might be a barrier. This could be relieved by creating artificial islands that use the ocean energy to produce desalinated water, hydrogen, and biomass (micro algae), which can then be shipped to the mainland.

Testing and development

A barrier for further development of ocean energy is the acute lack of suitable small-sea test environments. There are only a few of those sites available in Europe, and there is currently no funding available for building additional ones.

Once the technologies are sufficiently tested, the ocean energy market could grow mature rather quickly, as there is no such extensive up-scaling phase required as with wind power. Moreover, the integration into the grid is supposed to pose fewer problems, since waves are more predictable than wind. A wave power station can reach an annual production equivalent to 4000 hours at full capacity and it can be in service during 80% of the time.

More difficult to predict is the cost development of ocean energy. In any case, larger production volumes will be required to bring down the installation cost.

Technology challenges

- main challenges of OE systems design is to achieve:
  - high reliability and survivability
  - market levels for cost of energy

- commercially viable leading technology is yet to evolve
- contrary to wind different OE conversion technologies will be used at different locations.

2.5.4 **Additional benefits regarding low carbon society**

Ocean energy is particularly promising for supplying remote islands with a combination of electricity and desalinated water.
Furthermore, the production of biomass (algae) and hydrogen is also possible.

2.6 FUELS: Combined heat and power (CHP) generation

Cogeneration, also known as combined heat and power (CHP), refers to any system that generates electricity and heat in a single process. A cogeneration plant offers the additional advantage that the waste heat from the generation process can be used beneficially rather than rejected to the environment. This heat can be used in industrial processes or to provide heat to local communities.

CHP systems can be employed over a wide range of sizes, applications, fuels and technologies. In its simplest form, it employs a gas turbine, an engine or a steam turbine to drive an alternator, and the resulting electricity can be used either wholly or partially on-site. The heat produced during power generation is recovered, usually in a heat recovery boiler and can be used to raise steam for a number of industrial processes, to provide hot water for space heating, or, as mentioned above with appropriate equipment installed, cooling.

Because CHP systems make extensive use of the heat produced during the electricity generation process, they can achieve overall efficiencies in excess of 70% at the point of use. In contrast, the efficiency of conventional coal-fired and gas-fired power stations, which discard this heat, is typically around 38% and 48% respectively, at the power station. Efficiency at the point of use is lower still because of the losses that occur during transmission and distribution.

2.6.1 State of the art

<u>NL situation[20]:</u> In the Netherlands the size of industrial CHP plants range from 10 – 100 MW and their electrical efficiencies from 30-35%. The progress is largely dedicated to the replacement of old CHP plants with modern CHP plants.
CHP plants constitute 40% of the total installed power, according to 'Cogen Nederland', and contributes 30% towards the electricity production in the Netherlands, the largest percentage in Europe.

<u>UK situation[15]:</u> The latest statistics show little change in installed CHP capacity during 2005 with an increase of only 108 MWe between 2004 (5,684 MWe) and 2005 (5,792 MWe) across some 1,534 schemes, a net increase of 7 schemes. There were 29 new schemes that came into operation, whereas 22 schemes ceased operation. In terms of electricity generated; CHP contributed 30,340 GWh in 2005, representing 7.5% of the total electricity generated in the UK, and increase from 2004, where CHP generated 28,065 GWh or nearly 7% of total UK electricity generation.

An increasing number of CHP installations continue to be fuelled by natural gas. In 2005, this fuel accounted for 67% of fuel, up from 64% in 2004. New developments in CHP technology have opened up opportunities for using other fuels and in 2005, non-conventional fuels (landfill and sewage gas, fuel and gas oils, coal, lignite and coke, biomass and biogas, liquid, solid or gas by-products, waste products or renewable fuels, waste process heat) contributed 27% of all fuels used in CHP. This represents an increase from 2004, where such fuels accounted for 25% of fuels used.

2.6.2 Impact/Potential on electricity generation and infrastructure

NL situation[14]: In Figure 11 the development of the three main types of CHP, namely district heating, industrial CHP and gas engine for utilities and greenhouses is shown.

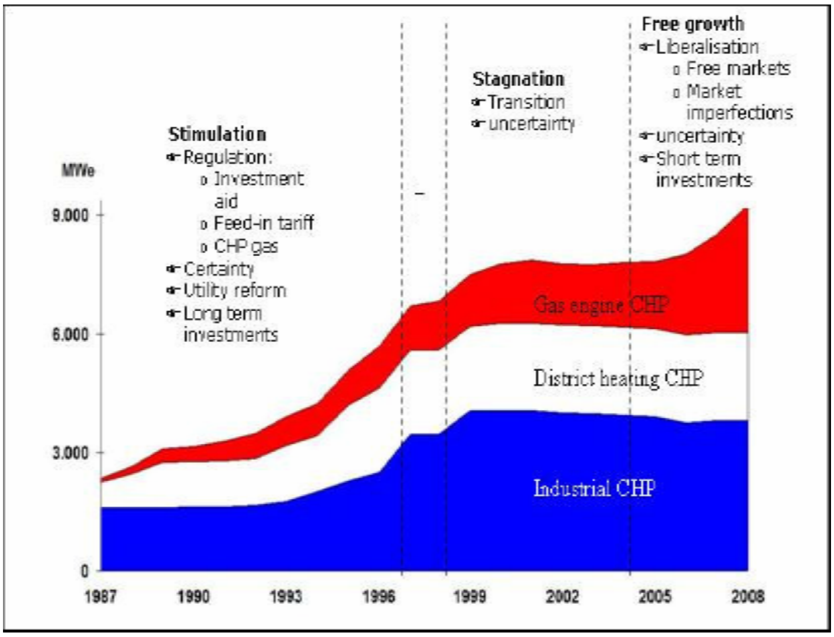


Figure 11 CHP development in industry, district heating, and gas engine application

The current growth of CHP in the Netherlands is mainly due to the significant application of CHP in greenhouses. In this sector the installed power has grown to approx. 2500 MWe. In the industrial and district heating applications the growth has been far less, even slightly negative growth can be seen. The estimated total production of CHP in the year 2007 is 55 TWh.

UK situation[15]: In terms of number of installations, the UK market is dominated by installations with an installed electrical capacity of less than 1 MWe, however schemes larger than 10 MWe represent more than 80 per cent of the total electrical capacity. CHP operates across all of the main economic sectors in the UK, with 407 installations in the industrial sector, representing 94 per cent of electricity capacity, the majority of which are found in four industrial sectors; chemicals, oil refineries, paper, publishing and printing and food. The remaining 6 per cent of capacity over some 1,127 schemes are spread across the agricultural, commercial, public administration, residential and transport sectors.

As with larger scale power generation technologies, efficiency and environmental performance continue to improve. Looking ahead there are several likely developments to note:

- fuel-cell CHP: offers the opportunity for higher levels of power efficiency in the range 50-60% (See also Section 2.7)
- micro-CHP: a range of technologies including stirling engines and fuel cells are being developed to provide a CHP package for individual homes
- renewable energy: a number of technologies are being developed which will assist the use renewable fuels for CHP. These include the use of gasifiers to convert biomass fuels for use in gas engines, gas turbines or fuel cells.

These developments mean that it is likely that CHP systems will retain or enhance their advantages of high efficiency and low environmental impact.

2.6.3 Challenges faced

Mainly through the liberalisation of the electricity market CHP systems are not implemented that often any more. However, government incentives, such as removing the tax levied on gas usage for CHP and other investment incentives aim to turn this situation around.

The current economic climate, low electricity prices and high gas prices, prohibit the large-scale deployment of CHP systems. Political incentive will be required to make CHP plants economically feasible in the near future.

2.6.4 Additional benefits regarding low carbon society

CHP delivers a range of economic and environmental benefits - some of these accrue to its users, some to operators of the electricity grid and yet others to the wider community:

Cost savings: CHP's high efficiency leads to a reduction in the use of primary energy. Precious fuels are used much more efficiently, so less is used. And less fuel used means significantly lower energy costs to the end user. Savings vary, but can be between 15% and 40% compared to imported electricity and on-site boilers.

Lower emissions: less fuel burnt means reduced emissions of carbon dioxide (the main greenhouse gas) and other products of combustion. Indeed CHP could provide the largest single contribution to reducing carbon dioxide emissions. Host organisations that wish to reduce their environmental footprint benefit - as does the environment.

Increased security and power quality: CHP systems can be designed to continue to operate and serve essential loads during an interruption to mains power supplies, increasing security of energy supplies. CHP can also supply higher-quality power than that from the grid - this can be important for computer data centres etc.

Grid reinforcement: siting an on-site CHP unit within the electricity grid can strengthen the network and remove the need for network operators to upgrade the system there.

Carbon emission savings from CHP in the Netherlands is appreciable. In 2007, CHP saved 10 million tonnes of carbon and saved 100 PJ of energy – the equivalent of 3 billion cubic meters of natural gas, or 4000-5000 MW of off-shore windpower. The potential savings for CHP is far from depleted. Moreover, it is expected that a doubling of the currently installed CHP power is possible. The Dutch governement has launched a program called 'Schoon en Zuinig' in which another 50PJ of energy will be saved due to a significant increase of CHP.

Carbon emission savings from CHP in the UK situation is also appreciable. In 2005, CHP saved 0.84 million tonnes of carbon per 1,000 MWe installed capacity against a fossil fuel basket, and 0.61 million tonnes of carbon per 1,000 MWe installed capacity against the total basket. These figures are an increase from 2004, where the equivalent figures were 0.79 million tonns of carbon /MWe and 0.58 million tonns of carbon/MWe respectively.

2.7 FUELS: Fuell cell power generation

A fuel cell is a device that allows hydrogen and oxygen to be combined to produce electricity – the reverse of the electrolysis process. A fuel cell works much like a battery. In both batteries and fuel cells two electrodes, an anode and a cathode, are separated by an electrolyte, see Figure 12. A storage battery is a sealed unit, containing all the substances in the electrochemical oxidation-reduction reactions involved and has, therefore, a limited capacity. In contrast, a fuel cell is supplied with its reactants externally and operates continuously as long as it is supplied with fuel.

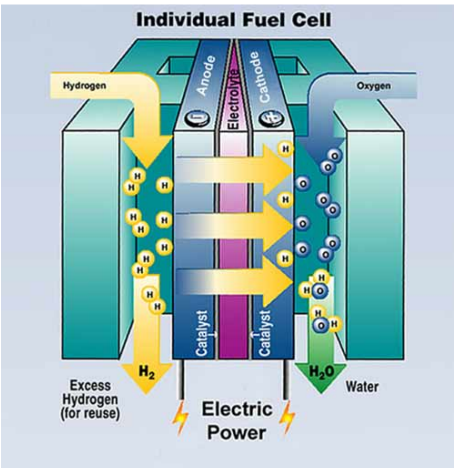


Figure 12 Fuel cell energy conversion concept

The five basic types of fuel cell are classified by the electrolyte that they employ:
- low temperature types include the alkaline fuel cell (AFC) and solid polymer fuel cell (SPFC)
- the medium temperature type is the phosphoric acid fuel cell (PAFC)
- the two high temperature types are the molten carbonate fuel cell (MCFC) and the solid oxide fuel cell (SOFC).

Oxgen from air is the oxidant (cathode fuel) in all these, but a number of fuels can be 'burned' at the anode.

2.7.1 State of the art

Various fuel cell types have been identified for large-scale stationary power generation, viz. PAFC, MCFC and SOFC and, more recently, PEMFC.

- Phosporic Acid Fuel Cells (PAFC): PAFC's have been developed to the first stages of commercialisation. Turnkey 200 kW plants are available and hundreds have been installed in Europe, USA and Japan. With an operating temperature around 200°C there is potential for hot water supply as well as electricity depending on the matching of the heat and electricity load profiles. Electrical efficiencies can exceed 40%.
- Molten Carbonate Fuel Cells (MCFC's): MCFC's offer higher fuel-to-electricity conversion efficiencies up to 60%. At operating temperatures of around 650°C the waste heat produced can be used in conventional combined cycle plant for the generation of more electricity via steam turbines thus raising the overall combined station efficiency. An important requirement of MCFC's is that operation is not affected by carbon monoxide or carbon dioxide in the fuel gas. At 650°C the carbonate salts of the electrolyte are in a liquid state allowing ion transport. At the anode the carbonate ions react with the hydrogen fuel to produce electrons for the external circuit, carbon dioxide and water; the cathode is supplied with oxygen and carbon dioxide and it is important that the correct amount of carbon dioxide is supplied and re-circulated in order to replenish the electrolyte.
- Solide Oxide Fuel Cells (SOFC's): SOFC's are solid state devices operating at temperatures up to 1000°C with a potentially wider choice of fuels without having to manage liquid electrolytes. Current is conducted by the passage of oxygen ions through a solid electrolyte. At the cathode oxygen is reduced to form oxygen ions; at the anode the transported oxygen ions react with the gaseous fuel to produce electrons for the external circuit and water. Generally fuel flow is used to regulate electrical output and air flow controls the temperature. SOFC's must operate at high temperatures to enable diffusion of oxygen ions through the electrolyte made possible by reason of oxygen vacancies in the electrolyte crystalline structure. With conventional designs the anode is a composite of nickel and yttria-stabilised zirconia (YSZ). This composite is an electron conductor (due to nickel) and also an ionic conductor (due to YSZ). Nickel, however, catalyses the formation of graphite from hydrocarbons, thus carbon formation with nickel based anodes is unavoidable for the wider range of hydrocarbon fuels available. Research suggests that anodes made from a composite of copper and ceria, or samaria-doped ceria, may remove this barrier in the future. Electrical efficiency is up to 60% and, again when used with combined cycle plant, higher overall station efficiencies can be obtained. These cells may be able to reform hydrocarbon fuels internally with no pumps required to circulate hot electrolyte and although still at a relative early stage of development they are regarded as most promising for generating electricity from hydrocarbon fuels.

2.7.2 **Impact/Potential on electricity generation and infrastructure**

Given the cost reductions in time associated with maturing technologies allowing fuel cells to be competitive with conventional generation plant, these stationary fuel cells fully developed and deployed within the electricity supply industry will have significant impacts and advantages compared with conventional generating plant, in terms of:

- emission reduction (NOx, SOx, CO_2, hydrocarbons)
- fossil fuel saving through higher efficiencies if used to replace older conventional fossil fuel plant – although modern 60% efficient Combined Cycle Gas Turbine (CCGT) stations are more efficient than either PEMFC or PAFC
- thermal recovery of high grade heat for CHP schemes
- planning flexibility in plant size without loss of efficiency
- high reliability
- quietness of operation
- suitability for embedded generation in either high demand or remote areas.

MCFC and SOFC plants are expected to be commercially available in the coming years, initially with 20 MW capacity and fuelled by natural gas.

2.7.3 **Challenges faced**

The development of fuel cells has been constrained primarily by the difficulty of making them cost effective and durable. However, hurdles vary according to the application in which the technology is employed. Size, weight, and thermal and water management are barriers to the commercialization of fuel cell technology. In transportation applications, these technologies face more stringent cost and durability hurdles. In stationary power applications, where cogeneration of heat and power is desired, use of PEM fuel cells would benefit from raising operating temperatures to increase performance.

The key challenges include:

<u>Cost.</u> The cost of fuel cell power systems must be reduced before they can be competitive with conventional technologies. Currently, the costs for automotive internal-combustion engine power plants are about €20–€30/kW; for transportation applications, a fuel cell system needs to cost €25/kW for the technology to be competitive. For stationary systems, the acceptable price point is considerably higher (€350–€700/kW for widespread commercialization and as much as €1000/kW for initial applications).

Durability and Reliability. The durability of fuel cell systems has not been established. For transportation applications, fuel cell power systems will be required to achieve the same level of durability and reliability of current automotive engines and the ability to function over the full range of vehicle operating conditions (40°C to 80°C). For stationary applications, more than 40,000 hours of reliable operation in a temperature at -35°C to 40°C will be required for market acceptance.

Air, Thermal, and Water Management. Air management for fuel cell systems is a challenge because today's compressor technologies are not suitable for automotive fuel cell applications. In addition, thermal and water management for fuel cells are issues because the small difference between the operating and ambient temperatures necessitates large heat exchangers.

Improved Heat Recovery Systems. The low operating temperature of PEM fuel cells limits the amount of heat that can be effectively utilized in combined heat and power (CHP) applications. Technologies need to be developed that will allow higher operating temperatures and/or more-effective heat recovery systems and improved system designs that will enable CHP efficiencies exceeding 80%. Technologies that allow cooling to be provided from the low heat rejected from stationary fuel cell systems (such as through regenerating desiccants in a desiccant cooling cycle) also need to be evaluated.

2.7.4 Additional benefits regarding low carbon society

While fuel cells have been used in niche applications for many years, mainly as standby electrical power supply units, recent improvements in their cost and efficiency are leading to future uses in the much larger market of 'zero emission' vehicles (ZEVs), see also Section 4.2. The new generation of fuel cells will probably also find other applications, such as in small (3-10 kW) combined heat and power (CHP) units, see also Section 2.6.

3 LOW-CARBON ELECTRICITY NETWORKS

Low-carbon electricity networks focus on combining renewable energy resources, commonly in a decentralised manner, to make intelligent use of the existing infrastructure and seamlesly evolve into a smartgrid infrastructure. Keeping the quality of supply the same, or even higher, than before.

3.1 SmartGrids[26]

A suggested definition of a smart grid is as follows, also see Figure 13:

> *"A smart grid generates and distributes electricity more effectively, economically, securely, and sustainably. It integrates innovative tools and technologies, products and services, from generation, transmission and distribution all the way to customer appliances and equipment using advanced sensing, communication, and control technologies. It enables a two-way exchange with customers, providing greater information and choice, power export capability, demand participation and enhanced energy efficiency."*[11]

Figure 13 the SmartGrids vision as illustrated by the European SmartGrid technology platform[6]

The consensus on the likely form and content of Smart Grid networks can be described at a high level.

The key descriptors that are anticipated for such grids in the context of large power systems:
- centralised plus de-centralised generation
- pan-EU interoperability: power flows & services
- bottlenecks and loop flows minimised or eliminated
- two-way distribution network flows
- less distinction between Transmission & Distribution
- customer information displays
- customer interaction and participation
- variability & intermittency of generation sources
- customers rewarded for exported power & services
- internet-like' architecture: dispersed intelligence and power flows from transmission level to distribution level, distribution level to transmission level and from consumer to consumer.

These capabilities cannot be achieved efficiently with today's network and communication architectures, or today's range of power system and consumer equipment and facilities. It is the view of the EU Technology Platform however that there is much potential technology which is close to commercial readiness and does not need fundamental research to achieve successful application in the next 5 to 10 years. There are also areas that require more fundamental attention and these will need to be addressed to provide the seed corn for the future.

The smart grids enabling technologies include the following:
- control of bulk power transfers
- renewable generation large scale
- renewable generation small and micro scale
- combined Heat and Power integration
- smart meters and interfaces
- intelligent Appliances
- transaction & Settlement systems
- ICT & Power Electronics
- bulk energy storage
- integration of electric vehicles
- integration of the Built Environment.

SmartGrids will help achieve sustainable development. Links will be strengthened across Europe and with other countries where different but complementary renewable resources are to be found. An increasingly liberalised market will encourage trading opportunities to be identified and developed. SmartGrids networks will, in addition to electricity flows, establish a two-way flow of information between supplier and user.

For a successful transition to a future sustainable energy system all the relevant stakeholders must become involved: governments, regulators, consumers, generators, traders, power exchanges, transmission companies, distribution companies, power equipment manufactures and ICT providers. Coordination at regional, national and European levels is essential and the SmartGrids Technology Platform has been designed to facilitate this process.

The benefits of new technologies will have a positive effect for European citizens and for international business. Job opportunities will be broadened as the networks require workers with new skills and integration across new technology areas.

It is evident that a lot of things will be changing in the electric power supply of the future. For example, houses will become more sustainable and mobility will merge with electricity supply through electric vehicles (see also Section 4.2).

As the definition of smart grids above already mentions, smart grids is not only about distribution networks but also about transmission networks and that the balance between reliability, affordability and sustainability is gradually changing over time due to a.o. customer demand. For any smart grid concept to work it is important to keep the customer satisfied at all times.

Pier Nabuurs, Chairmen of the SmartGrids technology platform[6] estimates the cost associated with:

- ageing assets
- infrastructure expansion
- the integration of renewable energy resources and distributed generation

in European transmission and distribution grids, until the year 2030, will amount to approximately 500 billion Euro.

3.2 Quality of electrical energy supply[27]

3.2.1 Impact/Potential on electricity generation and infrastructure

Quality of supply (QoS), an important performance indicator, is the measure showing the quality of electricity supplied to customers.

Quality of supply has been an issue for over 50 years. Due to a rapidly evolving environment (appliances, digital society), managing it in a competitive industry without major regulations is a challenge.

Supply to customers may be stopped or reduced or may fluctuate due to various *operational issues,* or *environmental issues*, such as fires, wildlife impacts, invasive plants, lightning, abnormal weather conditions, for example.

Three aspects of quality of supply can be defined:
Continuity of supply (availability): is fundamentally an engineering issue, being a function of network design, state of maintenance and investment. It is partially regulated.

Voltage quality: is also an engineering issue, being a function of network impedance, load distribution and planning. It is standardised but not regulated.

Commercial quality: focuses on service response, customer relations, dispute resolution performance and price. It is regulated.

Today, with many generators, suppliers, distribution network operators (DNOs), increasing number of customers and a future bidirectional flow of energy due to decentralised generation (DG), the current system raises the following issues for each party involved.

From a consumers point of view, the key is to have the appropriate availability of their own facility appliances and system and so every case is singular, moreover:
- electricity is just another raw material
- QoS data relates to availability, but dips are equally or more important to consumers
- consumers have different dependencies, cost bases and attitudes to investment
- consumers' losses are difficult to assess, even post event - published data tends to emphasise the extreme
- published data is aggregated and distant. Customer effects are highly localised

The suppliers are coping with having inherited ageing networks and face the situation that local upgrades are difficult to justify financially, moreover:

- ageing of infrastructure, cost of replacement
- change in industrial demographics and geography of energy consumption
- long feedback time to judge effectiveness of actions. The effect of local interventions may not be apparent in the reported data, financial justification is difficult.
- many desirable actions have long financial payback times
- price regulation versus investment.

From a regulators point of view, the lack of accurate data proves to be the bottleneck, moreover:

- interruption duration data is not accurate - especially start time
- very short interruption and dip data is not generally available
- relationship between cost/benefit of improvements is far from clear
- long feedback time for improvement initiatives
- price regulation v. investment.

As regards optimum supply, ultimately the customer has the lead in having a planned approach to power quality in order to measure, assess, identify and mitigate power quality issues in coordination with its own specific requirements.

Solving power quality issues at a costumer site is a major economic priority. An European survey - LPQI PQ Survey, encompassing samples drawn from 16 industries which together account for 74% of EU-25 financial output, together with 68 face to face interviews in 8 countries – has indicated that poor power quality costs the EU community approximately €150 billion per year.

3.2.2 Challenges faced

In the future, the move to a low carbon future may prevent stakeholders to invest in QoS improvement and so reliability will decrease. Therefore, it is expected that the industry will strongly benefit from the implementation of a simple classification scheme[12] (see Figure 14) to plan effective improvement.

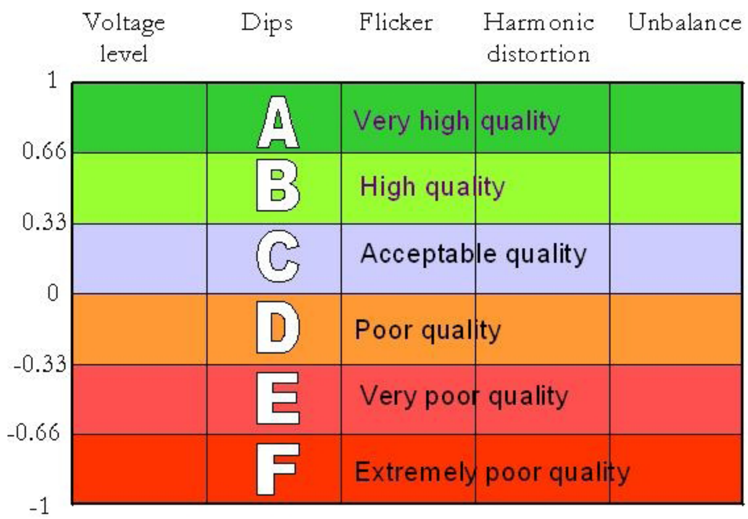


Figure 14 Classification of power quality phenomena[12]

On the other hand, we have reached an era where equipment can be made more resilient by improving voltage tolerance, using ultracapacitors and 3-phase supplies for control equipment.

The key challenges remaining are:
- lack of awareness of need to measure and monitor
- poor correlation between observed problem and the chosen solution
- investment in preventative measures is estimated at about €13 M - less than 10% of the cost of PQ losses
- education and information of both key actors.

Consumers need information to conform their expectations:
- baseline quality assurance
- by technical standard, not compensation
- classification of supplies
- classification of major PQ parameters against compatibility levels -eg Cobben and van Casteren
- plan installation and investment accordingly.

Future issues impacting Quality of supply will be frequency response, dispatchability, storage, DG, renewables. In this future system we need to overcome the current issues like poor power quality, lots of cost.

4 LOW-CARBON ELECTRICITY SERVICES

4.1 Electricity storage[24]

Electrical energy storage is defined as the conversion of electrical energy from a power network into a form in which it can be stored until converted back to electrical energy.

Energy storage offers benefits by "time shifting" electricity – allowing it to be produced at one time for consumption at another, and in doing so decoupling the electrical load from the electrical demand, see also Figure 15. Emerging energy storage technologies can have different applications within the electric grid system, delivering a number of different benefits in combination.

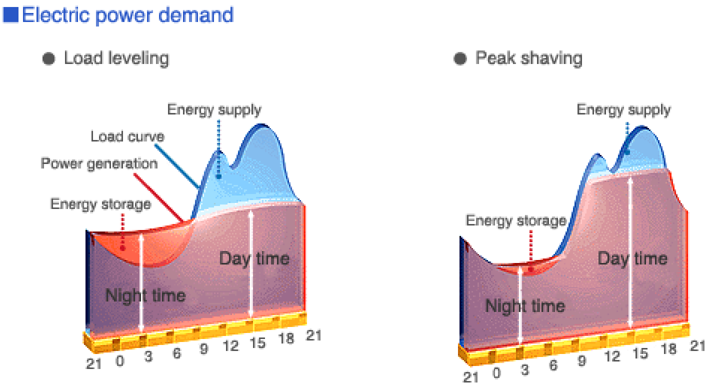


Figure 15 Time-shifting of electricity: load levelling vs. peak shaving

Electricity storage offers considerable added value for the energy sector, particularly when combined with wind power generating capacity on a large scale. Storage increases the technical reliability of the power supply, stabilizes the cost of electricity and helps to reduce greenhouse gas emissions.

Large-scale energy storage is already applied in many countries worldwide. Good results have been achieved with pumped storage facilities in countries like Germany, Austria, Norway, the UK and the USA. In the Netherlands, electricity storage is also attracting increasing attention, with concepts such as the energy island[26].

Storage can be implemented in mobile applications, see Section 4.2, or stationary applications. Storage for stationary applications can be used in many ways e.g. sustainable generation, smartgrids, risk management.

Storage is not considered to be a product per se, rather it provides functionalities and is considered more as a key value driver. The functionality of storage can be used e.g. for, arbitrage, peak shifting, bulk trading, regulating power (primary and secondary reserve capacity), investment deferral and ancillary services (Power Quality, see also Section 3.2) amongst others.

4.1.1 State of the art

A generic subdivision can be made for storage applied in stationary applications:
- transmission level (multi MW and multi MWh)
- distribution level (100’s kW-MW and 100’s kWh-MWh)
- ancillary services (Multi MW, 100’s kWh).

It is important to note that large scale storage often requires different technology than small scale and should therefore be considered differently.

The existing, technically proven, methods of energy storage that are capable of operation at a utility-scale are:
- pumped hydro;
- CAES (compressed air energy storage);
- battery types such as lead acid, nickel cadmium and sodium sulphur;
- super capacitors (low energy (Wh/kg) but lots of power),
- redox flow systems and
- flywheel systems.

The costs of energy storage depends on the technology used, the energy content (hours or several weeks) and the power conversion system. Ballpark figures of costs are roughly: 1 kEuro / kWh and 100 – 1000 Euro/ kW. Both must be taken into account when calculating the costs of energy storage.

4.1.2 Impact/Potential on electricity generation and infrastructure

For the next decade energy storage will enhance the value of renewable energy. It will become a major source of ancillary services and will be a key enabler for smart grid technologies.

Moreover, as increasing amounts of large-scale centralized renewable generation as well as small-scale distributed generation – especially wind and solar – are added to the grid, it may be necessary for the plants to meet additional requirements to help maintain reliable grid operations. Storage can be utilized to mitigate ramping issues as well as a number of revenue services for the operator.

Emerging energy storage technologies offer a viable solution for renewable and distributed generation grid integration. Advanced energy storage technologies, with the ability to provide fast-acting energy storage for regulation service, also show promising potential for enhancing grid reliability.

4.1.3 Challenges faced

Key questions for the development of ES in grids are:
- does regulation allow the connection of storage to the grid?
- what schemes are in place to allow for payment?
- allocation of benefits (technical and monetary).

4.1.4 Additional benefits regarding low carbon society

Additional emission benefits can also be captured when storage replaces traditional fossil generation for these roles. As storage gets its charge from the grid, utilizing storage technologies can help reduce the overall amount of emissions such as CO_2, NOx, and SOx when compared to fossil fuel generation. For applications such as frequency regulation, KEMA studies have shown that storage can provide lower emissions and a lower life-cycle cost when compared to some fossil plants performing similar roles.

4.2 Electrification of transport[25]

Electric vehicles are on the brink of revolutionizing the automotive market, again! In 1899 and 1900 electric vehicles (EVs) actually outsold any other vehicles.

Electric vehicles, see Figure 16, have far higher “well to wheel efficiency” than traditional ones; and from the various energy carriers, electricity is the only available that delivers both low emissions and large scale. When comparing the production of traction energy from electricity to that of hydrogen, electricity with an efficiency of 69% is appreciably higher than the 24% for hydrogen. Furthermore, electricity features:

- low emissions
- favourable scale (is already large)
- already available today (100%).

Figure 16 Examples of electric vehicles connected to the grid

Enexis, a Dutch grid operator, has launched the mobile smart grid initiative, in which the technology advances in both the electrical vehicles and the grid interface is stimulated and researched.

A parallel can be drawn between the evolution that the telephone system has experienced the last decade, evolving from a predominantly fixed system to a significant mobile system, and power grids, currently evolving from a predominantly fixed system to perhaps a more mobile smart grid via electric vehicles for example.

In this project Enexis is planning on increasing their own electrical vehicle fleet from 10 EV at present to 70 in the year 2010, as well as incorporate a number of hybrid vehicles.

4.2.1 State of the art

While many pilot projects are underway to demonstrate the value of EVs and build a market, many reservations are raised concerning overloading of electricity networks, performance/reliability of EVs or even resource availability for battery manufacturing.

It is predicted that should the national car fleet in the Netherlands be electrified for 20%, i.e. 20% of the current fleet is replaced by electrical vehicles, and there is no regulation on charging, then the energy demand peak will already double, while there would be much free capacity at non-peak hours. However, by allowing the electrical vehicles to charge over a 24 hour period, the existing electrical production and transport capacity is sufficient to charge a fleet consisting of 75% electrical vehicles, see Figure 17.

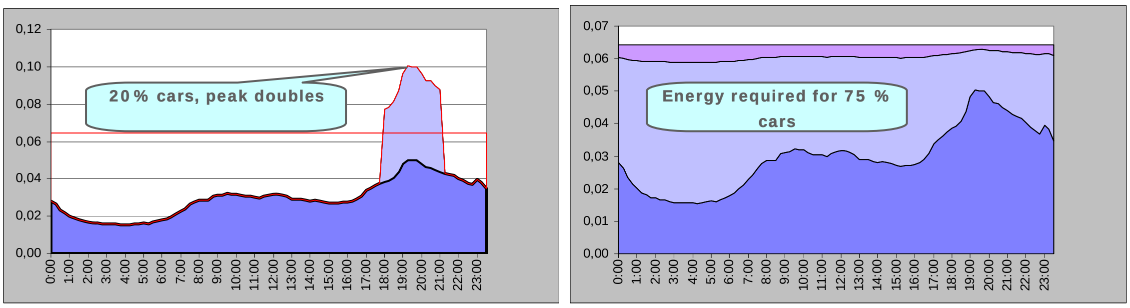


Figure 17 Impact of electrical vehicles on the grid, without (left) and with controlled charging

Current free capacity represents about 70GWh, enough for roughly 350,000,000 km/day, equivalent to about 5,000,000 commuters.

Electrical vehicles are to be regarded as "distributed" or "transportable" storage, from a grid operators point of view.

4.2.2 Impact/Potential on electricity generation and infrastructure

Grid operators play an essential role on making this energy transition possible, but to make electric vehicles a success, utilities, car industry and public authorities must work together to overcome these obstacles.

The mobile smart grid project concept enhances optimal use of the existing grid by coupling the grid and EVs, combining several control layers to maintain system balance and optimize network utilization. In this sense, to facilitate integration, standardization for charging points (charger and connector), physical protection, most important communication for charging control, etc. is an imperative step.

The most challenging problem at hand is for electrical vehicles to justify a network of charging points and vice-versa. Furthermore, consumers need to buy-in to the concept and purchase electrical vehicles.

With current concerns on sustainable/clean energy use, many incentives and a behavioural shift are imminent, unveiling a promising future for electrical vehicles.

In the Netherlands a government initiative has been launched to realise 10.000 electrical vehicle charging points within the Netherlands before the year 2012. The dutch branch organisation 'Netbeheer Nederland' has been ordered to define the regulation that is required for this to succeed.

4.2.3 **Challenges faced**

Enexis argues that the major challenge (and opportunity) lies in effectively managing the charging of electrical vehicles. With uncontrolled charging, a car park with 20% EVs could easily double peak demand in The Netherlands.

The challenge faced is more on the socio-economic level than on the technical level, and more on trading than grid balancing.

Challenges facing the grid operators, include:
- making the energy transition possible
- creating standards (cabling, charging, infrastructure,…)
- changing management (to avoid excessive grid investment)
- solving the chicken & egg problem: vehicle vs. grid vs. people (users).

Currently the restriction for consumers to invest in electric vehicles is the lack of clear incentive for the car owner himself.

4.2.4 **Additional benefits regarding low carbon society**

EVs produce zero emissions at the point of use.

EVs also run far more quietly than their combustion-powered counterparts which enhances health and comfort.

4.3 Heat pump technology[8]

Heat flows naturally from a higher to a lower temperature. Heat pumps, however, are able to force the heat flow in the other direction, using a relatively small amount of high quality drive energy (electricity, fuel, or high-temperature waste heat). Thus heat pumps can transfer heat from natural heat sources in the surroundings, such as the air, ground or water, or from man-made heat sources such as industrial or domestic waste, to a building or an industrial application. Heat pumps can also be used for cooling. Heat is then transferred in the opposite direction, from the application that is cooled, to surroundings at a higher temperature. Sometimes the excess heat from cooling is used to meet a simultaneous heat demand.

In order to transport heat from a heat source to a heat sink, external energy is needed to drive the heat pump. Theoretically, the total heat delivered by the heat pump is equal to the heat extracted from the heat source, plus the amount of drive energy supplied. Electrically-driven heat pumps for heating buildings typically supply 100 kWh of heat with just 20-40 kWh of electricity. Many industrial heat pumps can achieve even higher performance, and supply the same amount of heat with only 3-10 kWh of electricity.

Because heat pumps consume less primary energy than conventional heating systems, they are an important technology for reducing gas emissions that harm the environment, such as carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NOx). However, the overall environmental impact of electric heat pumps depends very much on how the electricity is produced. Heat pumps driven by electricity from, for instance, hydropower or renewable energy reduce emissions more significantly than if the electricity is generated by coal, oil or gas-fired power plants.

4.3.1 State of the art

Almost all heat pumps currently in operation are either based on a vapour compression, or on an absorption cycle.

Vapour compression: The great majority of heat pumps work on the principle of the vapour compression cycle. The main components in such a heat pump system are the compressor, the expansion valve and two heat exchangers referred to as evaporator and condenser. The components are connected to form a closed circuit, as shown in Figure 18. A volatile liquid, known as the working fluid or refrigerant, circulates through the four components.

Absorption: Absorption heat pumps are thermally driven, which means that heat rather than mechanical energy is supplied to drive the cycle. Absorption heat pumps for space conditioning are often gas-fired, while industrial installations are usually driven by high-pressure steam or waste heat, see Figure 18.

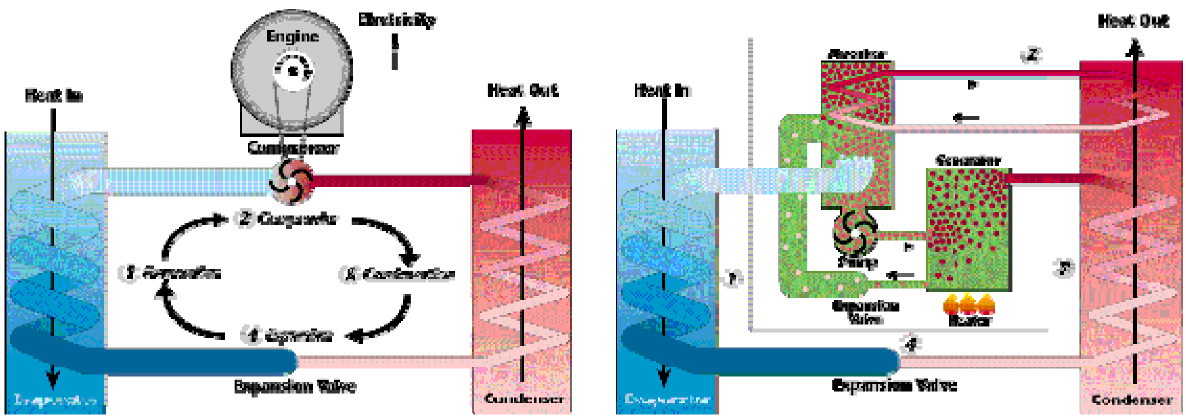


Figure 18 Closed cycle, electric-motor-driven vapour compression heat pump (left) and Absorption heat pump (right) concepts

Relatively few heat pumps are currently installed in industry. However, as environmental regulations become stricter, industrial heat pumps can become an important technology to reduce emissions, improve efficiency, and limit the use of ground water for cooling.

Industrial applications show a great variation in the type of drive energy, heat pump size, operating conditions, heat sources and the type of application. The heat pump units are generally designed for a specific application, and are therefore unique.

The major types of industrial heat pumps are:
- mechanical vapour recompression
- closed-cycle compression heat pumps
- absorption heat pumps
- heat transformers
- reverse Brayton-cycle heat pumps.

Industrial heat pumps are mainly used for:
- space heating;
- heating and cooling of process streams;
- water heating for washing, sanitation and cleaning;
- steam production;
- drying/dehumidification;
- evaporation;
- distillation;
- concentration.

4.3.2 Impact/Potential on electricity generation and infrastructure

Existing and upcoming EU legislation will spur the use of renewable energy solutions, most therefore also heat pumps.

Three main drivers in the EU for heat pumps using natural refrigerants can be identified:
- the targets set under the Kyoto Protocol to reduce GHG emissions by 2012
- the F-Gases Regulation restricting the use of fluorinated gases in heat pump applications
- soaring energy prices.

The use of heat pumps using natural refrigerants is seen as the most viable solution to comply with legal requirements. However, heat pump manufacturers would have to play their part in promoting the systems to consumers and industry players in the EU. More importantly, heat pumps should be more present on political agendas.

By 2030, the annual carbon emissions of heating a typical EU home could decrease from 8 to 1 tonne only by using a heat pump system. These savings will be essential in meeting not only Kyoto goals but also ensuring energy supplies beyond 2010. By then, the oil and gas supplies will peak with an annual decline of up to 3% after that. As a consequence, the heating and cooling market must transform away from oil and gas, moving to more sustainable solutions. As has been shown by latest studies of Eurelectric – the representative of all major electrical utilities – heat pumps will be key in reducing energy use.

4.3.3 **Challenges faced**

Experiences so far have shown the viability of CO_2 heat pumps in tap water and space heating. Japanese hot water “EcoCute” units installed in Sweden have been operating over a period of 4 years without any problems. At present, leading manufacturers are investing in R744 heat pumps in the EU, including Green&Cool, Bock, Dorin, Denso, Sanyo, and Stiebel Eltron.

The lack of suitable components is identified as a key obstacle for a wide-spread use of these systems. More specifically, heat exchangers are not available in the required quality. Several performed projects did not lead to high efficiency because of the low compressor performance that differed largely from the efficiency levels indicated by the manufacturer.

4.3.4 **Additional benefits regarding low carbon society**

If it is considered that heat pumps can meet space heating, hot water heating, and cooling needs in all types of buildings, as well as many industrial heating requirements, it is clear that heat pumps have a large and worldwide potential. Of the global CO_2 emissions that amounted to 22 billion tonnes in 1997, heating in building causes 30% and industrial activities cause 35%. The potential CO_2 emissions reduction with heat pumps is calculated as follows:

- 6.6 billion tonnes CO_2 come from heating buildings (30% of total emissions)
- 1.0 billion tonnes can be saved by residential and commercial heat pumps, assuming that they can provide 30% of the heating for buildings, with an emission reduction of 50%
- a minimum of 0.2 billion tonnes can be saved by industrial heat pumps.

The total CO2 reduction potential of 1.2 billion tonnes is about 6% of the global emissions. With higher efficiencies in power plants as well as for the heat pump itself, the future global emissions saving potential is estimated at 16%.

In some regions of the world, heat pumps already play an important role in energy systems. But if this technology is to achieve more widespread use, a decisive effort is needed to stimulate heat pump markets and to further optimise the technology. It is encouraging that a number of governments and utilities are strongly supporting heat pumps. In all cases it is important to ensure that both heat pump applications and policies are based on a careful assessment of the facts, drawn from as wide an experience base as possible.

5 FINAL REMARKS

This white paper provides an overview of the most promising technologies that could contribute towards a low carbon electricity system within the timeframe of the next decade.

Besides addressing the state of the art of each technology and the (predicted) impact thereof on the energy system of the future, the challenges being faced by each is also mentioned. This to provide insight in the bottlenecks keeping us from a smooth transition into a more smart and low carbon energy system.

In an attempt to answer the two main questions posed, namely: What action should be taken to accelerate the move towards low carbon electricity? What are the options for policy makers and market players? The following should be taken under consideration.

When considering the technology overview provided herein, it is possible to identify the main challenges that span across multiple of these technologies. These are:

- cost, either in terms of financing of research, or in the cost of manufacturing equipment
- education and training of all parties involved, ranging from installers to regulators
- market awareness and public acceptance of new technologies invading their homes/lives
- the need for flexibility in the energy system
- to a lesser extent the technologies themselves, as it is expected that with innovation the technical barriers are solvable.

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