Hydropower electricity is the product of transforming potential energy stored in water in an elevated reservoir into the kinetic energy of the running water, then mechanical energy in a rotating turbine, and finally electrical energy in an alternator or generator. Hydropower is a mature renewable power generation technology that offers two desirable characteristics in modern electricity systems: first, built-in storage that enables electricity to be provided on demand and second, a fast response time that allows reserves to be fed into the grid.

Hydropower also has an important role to play in producing renewable electricity. It is low-cost and readily available: power flow is controlled through turbines to produce electricity on demand. In 2012, about 44% of the electricity generated from renewable energy sources, or roughly 10% of the total electricity production in the EU-27, came from hydropower.

The European countries with the largest installed hydropower capacity are Norway, France, Italy, Spain, Sweden, Switzerland and Germany.¹ Maintaining or upgrading the existing infrastructure is an important focus throughout Europe. The emphasis in Western Europe is retrofitting hydropower plants with modern equipment and upgrading capacities of plants. In Eastern Europe the focus is rehabilitating ageing plants that deteriorated during the Soviet era.

The technology

Hydropower is a mature renewable power generation technology that offers two very desirable characteristics in today's electricity systems: built-in storage that increases the system's flexibility, and a fast response time

¹ EU Energy in Figures 2013

Fact file

- Hydropower is the most widely used form of renewable electricity, with 3700 TWh generated worldwide in 2012.
- In 2012, hydropower provided an estimated 16.5% of the world's electricity. This share is expected to rise to 19% in 2020 and 21% in 2030.
- Hydropower accounted for 79% of all electricity produced from renewable sources globally in 2012.
- In at least 36 countries hydropower covers more than half of the electricity supply. In Norway, 95% of electricity supply comes from hydropower.
- Hydropower accounted for 44% of the electricity generated from renewable energy sources in the EU-27 in 2012 or 10% of the total electricity production. This is down from 65% in 2007.
- In the EU-27, gross production of hydroelectric installations amounted to about 330 TWh in 2012. Pumped storage output was about 31.2 TWh. According to Eurelectric, there is potential for a further 276 TWh of hydropower in the EU-27.
- Large hydropower (more than 10 MW) is well established in Europe. More than half of favourable large hydropower sites have been exploited across the EU-27.
- In the EU-27 about 21,800 small hydropower plants (SHP) are in operation with average sizes of 0.6-0.7 MW.
- The International Energy Agency (IEA) considers that only 5% of the world's small-scale potential is being exploited. It is thought that small hydropower potential could be increased to 200 GW.
to meet rapid or unexpected fluctuations in supply or demand.

Most hydropower generation originates in large conventional, reservoir-based plants providing either seasonal or inter-season reserves. A second hydropower technology is a run-of-river (RoR) plant where, instead of being stored, part of the normal flow of river water is diverted into a canal, which feeds a low-head turbine. Whereas a reservoir plant can run on demand, e.g. to cover peak electricity demand, run-of-river plants generate electricity depending on the water flow and thus provide base-load electricity. When demand for electricity is low, a pumped hydropower storage (PHS) facility stores energy by pumping water backwards from a lower reservoir (or river) to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir to generate electricity. World pumped-storage potential is approximately 1,000 GW.

Hydropower installations are usually classified as either large (over 10 MW) or small (less than 10 MW). The small hydropower (SHP) sector is differentiated between reservoir-based and RoR schemes.

The technical and economic performance of hydropower is very dependent on site specifications and utility operating strategies. Average load factors of large-scale hydropower plants range from 2,200 to 6,200 full-load hours per year in Europe (23 to 70%), with an average of 3,000 hours (35%) in Europe, with wide variations according to country.

Hydropower plants have a long asset life, with many facilities operating more than 50 years. Labour cost is low as facilities are automated and so few personnel are required on site.

Apart from the investment and production costs, the other principal cost element is operation and maintenance (O&M), including repairs and insurance, which can account from 1.5 – 5% of investment costs annually. Both the production and investment costs differ considerably depending on the head height of the plant.

Ongoing research

Despite being a mature technology, hydropower theoretically still has significant untapped potential, particularly in the development of new plants (very low head small hydro plants and pumped storage plants) and also in the upgrading of old ones (increasing efficiency and electricity production and environmental performance). However, at least in Europe, there is considerable public opposition to the construction of new dams and reservoirs.

Hydropower will continue to play a crucial role in the integration of fluctuating renewable energy sources by providing reserve, storage and balancing capacities for the European electricity grid. Research is also being directed at improving turbine design and investigating alternatives to steel, such as fibreglass and special plastics. Other considerations include faster ramp-up and ramp-down and higher efficiency at part load.

The eStorage project, supported by the Seventh Framework Programme (FP7) of the EU, started in 2012 with the objective of devel-
Hydropower is the major renewable electricity generation technology worldwide and will remain so for a long time. Since 2005, new capacity additions in hydropower have generated more electricity than all other renewables combined.

International Energy Agency (2012)

The industry

The global potential for conventional hydropower is thought to be around 9 770 TWh, with 3 700 TWh of capacity installed worldwide. This is expected to double to 7 000 TWh by 2050.

EU hydropower potential is already relatively well exploited and expected future growth is rather limited – to between 470 TWh and 610 TWh of total annual generation. The largest remaining potential in Europe lies in low-head plants (less than 15 metres) and in the refurbishment of existing facilities. Over half the favourable sites in Europe have already been exploited.

Europe has maintained a leading position in the field of hydropower manufacturing ever since the technology started to develop 150 years ago. By developing technology and production methods in a fast-growing home market, European manufacturers have maintained a leading manufacturing edge over other parts of the world. Very little non-indigenous equipment has been installed in European hydropower plants.

Three large European companies lead the large- to medium-scale hydropower market worldwide, namely Alstom Power Hydro, Andritz Hydro and Voith. Several European companies hold a recognised industrial position worldwide in the small turbine segment, which represents the bulk of the European market.

These industries are mainly located in Italy, France, Germany, Austria and Sweden, but are also well represented in the Czech Republic, Poland and Slovenia. The activity of all these companies is largely geared towards export.

Barriers

The main barrier to the further development of hydropower in Europe continues to be a lack of suitable sites, as most of these have already been developed. There are non-hydro reservoirs which could be adapted for hydropower use, and Member States could make an inventory of these to gain a clearer picture of the available resource.

The impact of large hydroelectric facilities on the environment is often significant. Small installations, on the other hand, involve minimal reservoir and civil construction work, so their environmental impact is relatively low.

Institutional barriers still exist which hamper development – for example, long lead times to obtain or renew concession rights; concessions locked to a holder that does not actually develop the scheme, and lack of grid connections.

Deployment costs

<table>
<thead>
<tr>
<th></th>
<th>Large Hydropower</th>
<th>Small Hydropower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost (EUR/kW)</td>
<td>730-2 550</td>
<td>1 310-5 330</td>
</tr>
<tr>
<td>Investment cost, EU (EUR/kW)</td>
<td>800-2 700</td>
<td>875-4 900</td>
</tr>
<tr>
<td>LCOE (EUR/MWh)</td>
<td>29-58</td>
<td>22-80</td>
</tr>
<tr>
<td>LCOE EU (EUR/MWh)</td>
<td>51-140</td>
<td>66-220</td>
</tr>
</tbody>
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Assuming 10% cost of capital, and annual O&M costs of 2% of the investment cost. Original figures in USD2011 converted to EUR2012.

- 13.7 GW of SHP installed capacity in the EU-27, generating 49.6 TWh of electricity in 2010.
- 95.6 GW of LHP installed capacity in the EU-27, generating 308.8 TWh of electricity in 2010².
- 29 000 direct employees in SHP, 57 000 in the hydropower sector as a whole (ESHA).

According to the National Renewable Energy Action Plans (NREAPs) agreed in 2010, EU-27 Member States have set a small- and medium- hydropower installed capacity target of 15.92 GW for 2020, excluding pumping. The interim target for 2015 is 14.39 GW.

² ESHA SteamMap project.
Administrative procedures take from 12 months to 12 years. The ratio of pumped hydropower capacity to total capacity varies among Member States from zero to 92%, which suggests barriers to pumped hydropower in certain countries.

Meeting environmental standards for water management can sometimes limit plant capacity, but is also a driver for innovation and improved performance. More efficient hydropower systems are required, for which R&D is vital, but hydropower is not seen as a political priority. Implementation of the EU Water Framework Directive (WFD) in Member States could decrease hydropower production.

Needs

The capital required for small hydro plants depends on the effective head, flow rate, geological and geographical features, the equipment (turbines, generators etc.), civil engineering works and continuity of water flow.

Making use of existing weirs, dams, storage reservoirs and ponds can significantly reduce both environmental impact and costs. It is estimated that in the USA only 3% of existing dams have hydropower exploitation, but a similar analysis does not exist for Europe.

Sites with low heads and high flows require a greater capital outlay, as larger civil engineering works and turbine machinery are necessary to handle the larger flow of water. If, however, the system can have a double purpose – combining power generation, e.g. with flood control, irrigation or drinking water supply – the payback period can be reduced.

Installed capacity

At the end of 2011, installed hydropower capacity in the EU-27 reached 106 GW, plus 43 GW of pumped storage, 675 MW of which was added in 2012. Most (90%) of the installed capacity is made up of large hydropower plants, with the remainder accounted for by some 21 000 SHP plants.

According to the European Small Hydropower Association (ESHA), 21 800 SHP were in operation in 2010, with an average installed capacity of 0.6-0.7 MW. The number of SHP could rise to 24 000 by 2020. Over one third of Europe’s SHP are in Germany, but Italy has the largest SHP installed capacity (2 735 MW in 2010). The total installed capacity of SHP plants in the EU-27 is about 13.7 GW.

The transformation of existing facilities into storage schemes is an important potential base for pumped hydro-storage development and there is also room for more innovative schemes e.g. using old mine pits or using the sea as one of the reservoirs.

For further information:

Section on SETIS website: http://setis.ec.europa.eu/technologies/Hydropower

European Small Hydropower Association http://www.esha.be