FACTS AND FIGURES

ELECTRICITY GENERATION 2013|2014
The global population is increasing by 83 million people per year, i.e., within roughly five decades, the number of people has doubled between 1960 and today.

At present, approximately one quarter of the global population of nearly 7.2 billion people does not yet have access to electricity. Electricity consumption will grow faster than any other form of energy consumption. The increase might be decelerated in the short term due to the worldwide financial and economic crisis, however, in the medium term the above-mentioned factors will again dominate the development. It is expected that the 2010 gross electricity consumption figures of 21,408 billion kWh will increase by roughly 71 % to 36,637 billion kWh worldwide by 2035. About 16 % of the electricity generated globally – roughly 3,346 billion kWh – was provided in the European Union (EU). A 0.8 % p. a. rise in demand is expected in the EU by 2035.

Experts estimate that fossil fuels will continue to cover most of the extra demand. Fossil fuels will still account for about 60 % of electricity generated worldwide in 2035. About half of the electricity generated in the EU will come from fossil fuels by that time. Renewable energy sources will play a growing role in the global primary energy consumption structure. Likewise, nuclear power will – despite the political nuclear phase-out in some countries – maintain an important position in global electricity generation and will even grow in some countries.
Expected growth in electricity generation in billion ($10^9$) kWh worldwide

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Generation</th>
<th>Wind, biomass, solar</th>
<th>Hydro power</th>
<th>Nuclear</th>
<th>Fossil</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>20,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2035</td>
<td>40,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+71 %

Expected growth in electricity generation in billion ($10^9$) kWh in the EU

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Generation</th>
<th>Wind, biomass, solar</th>
<th>Hydro power</th>
<th>Nuclear</th>
<th>Fossil</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>3,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2035</td>
<td>4,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+23 %

Source: IEA, VGB
Existing primary energy reserves and resources, in particular when including unconventional sources, are still sufficient in terms of fossil fuels and uranium around the world. Hard coal and lignite as well as uranium are the most widespread. However, energy sources have an uneven geographical distribution, which means that some countries and regions, including the European Union, are becoming increasingly dependent on imports. The EU’s fossil fuel reserves amount to about 38,000 million tonnes of coal equivalent (TCE), accounting for only 2.8% of the known reserves worldwide, and consist mainly of lignite and hard coal. The natural gas and oil reserves amount to approximately 6 billion TCE.

Europe’s dependency on imported coal will grow from about 40% today to more than 60% by 2030. An import dependency of 81% is expected for natural gas and of as much as 88% for oil. Overall, the share of imported energy will increase from about 50% today to roughly 70% by 2030. Underlying causes are the decreasing European energy reserves that can be produced at competitive prices. Lignite remains the only fuel that can still be mined from open cast mines at competitive costs in some countries in the long term.

Source: BGR, OECD-NEA, VGB

Reserves: Known and with current technology economically recoverable sources.

Resources: Reserves and documented but with current technology economically not recoverable sources.

Static range: As quotient of amount of reserves and/or resources and current consumption, it is a snapshot of the current state of knowledge.

Static range of energy sources worldwide as well as reserves and resources (in years)

- Oil: Conventional [41, 64] + Conventional + non-conv. [65, 160]
- Natural gas: Conventional [60, 135], Conventional + non-conv. [760, 2,840]
- Hard coal: 127 years
- Lignite: 260 years
- Uranium: <260 $/kg, advanced fuel cycles: 143 years

Graph showing static range of energy sources worldwide.
Regional distribution of the worldwide energy reserves for hard coal, lignite, oil, natural gas and uranium/thorium

- North America: 287 billion TCE
- Middle- and South America: 70 billion TCE
- Africa: 72 billion TCE
- Middle East: 245 billion TCE
- Asia, Oceania, Australia: 341 billion TCE
- CIS: 293 billion TCE

The area of the circles corresponds to the scope of regional energy reserves; the area of the circle segments corresponds to the regional share of each source of energy.

- Oil
- Natural gas
- Uranium/thorium
- Hard coal and lignite

TCE: tonne of coal equivalent
TOE: tonne of oil equivalent
1 TCE = 0.7 TOE

Source: BGR 2012
INVESTMENTS IN NEW POWER PLANT PROJECTS ARE AT RISK

The need to replace older power plants and the increase in electricity consumption in Europe made many companies to plan new construction projects. Despite the extensive increase in renewables, coal, natural gas, and nuclear power remain the most important primary energies for reliable and planable electricity generation. Highly efficient new plants replace older, less-efficient plants. And not only CO₂ emissions will be clearly reduced but other emissions related to fossil energy conversion will be decreased, too. However, investments in new-build projects in Europe become very sluggish because long-term politically reliable conditions are missing.

The emerging European generation gap can be closed only through the consequent realisation of the new announced power plant capacities to be constructed. VGB PowerTech updated the statistics on new build plants for the period 2007 to 09/2013. Accordingly, gas-fired power plants still have the largest share with some 30% (some 72,400 MW) in new build conventional plants, followed by nuclear power with a share of some 24% (57,200 MW). Hard coal and lignite-fired units are in the third place with a total share of some 14% (33,380 MW).

Wind power plants are still in the lead with some 23% (57,014 MW) in new build RES capacity.
The further extension of RES and the preferred consumption of RES-based power as practised in some European countries, results in a decline of thermal power plants with reliable utilisation schedules. Consequently, the power generation cost is increasing sharply for fossil power that is indispensable for system stability.

The power generation cost for a plant designed for base load operation with some 6,000 full load hours will increase by 100% if the plant is utilised for 2,000 full load hours only. If the plant is used even less, for e.g. some 1,000 full load hours, the cost will increase by the factor of 4.

The situation of poor plant utilisation has particularly negative impacts on highly efficient, state-of-the-at new power plants because they have to cope with extra financial burden caused by high fixed cost, i.e. interest and debt payments, and staff as well as maintenance costs.

New thermal power plants using fuels with highly fluctuating prices are also at additional economic risk. This was experienced by a lot of natural gas-fired power plants that could not be operated economically efficient although they are technically very efficient.

The mechanisms on the European energy market need to be reshaped in order to realise construction of new capacities, the utilisation of which will be reliable and which are urgently required as back-up.

The chart shows the cost of electricity (CoE) production in relation to operating hours. A substantial increase of fixed costs is indicated.
The EU member states set themselves ambitious targets for the extension of renewables.

Binding national targets were laid down in the EU Directive 2009/28/EG within a European framework supporting renewables in order to increase the share of RES in final energy consumption to 20% and in traffic to 10%. Wind energy e.g. is estimated to grow from 200 billion kWh in 2012 to some 495 billion kWh in 2020. However, according to current trends, these targets are likely not be fully met by 2020 unless administrative and infrastructure obstacles are eliminated and measures are taken in support of renewables. These are the results of a first progress report of the EU Commission on the extension of renewables.

Hydro power is still a reliable renewable source of energy. Pumped storage plants also play a very important role in the provision of reserve power/peak load and grid control. Numerous new hydro power projects as well as expansions and retrofits are being realised or planned for the near future, e.g. in Austria, Switzerland, Germany, and Portugal. Essentially, these will utilise more supplementary generation or (pumped) storage capacities by biomass, solar, geothermal, large hydro power, small hydro power, and wind.
expanding or optimising the plants at existing sites. An important step is also increasing plant efficiencies by replacing older machines and/or components by new, high-performance designs, thereby meeting the envisaged environmental protection requirements.

Utilisation of wind power is playing an important role in order to meet the targets of the European Union within the Climate and Energy Package by 2020. By the end of 2012 some 22,297 wind power plants were operated in Germany with a capacity of 31,308 MW. At that time, the installed capacity in Europe amounted to 109,581 MW and worldwide to 282,482 MW.

The technology needs to be advanced and developed consequently to increase technical availability of wind power plants. It is also urgently required to adjust wind farm operation to the methods that have been proven well with conventional power plants. Therefore, different VGB-Standards specify from the operators’ viewpoint the requirements for conventional power plants need to be transferred to the installation and operation of on- and offshore wind power plants. Standardisation is also to reduce costs of maintenance and repair. Consequent advancement of plant engineering is also of great importance. Apart from reliability, parameters like weight, cost, and efficiency are

![Wind: Development of electricity generation in the EU](image-url)
also crucial. In future, offshore plants will face more challenges due to increasing water depth and capacities. Besides, numerous questions of safety and maintenance have not been solved yet. This is revealed by experience made with offshore wind parks.

When assessing the national renewables action plans, it becomes clear that in addition to wind power, biomass-based electricity generation also has to be increased in order to meet the EU 2020 targets. Therefore, it is envisaged to increase the share of biomass electricity to 232 billion kWh by 2020. The European Commission recommended requirements to be met in connection with the use of solid and gaseous biomass fuels in electricity generation, heating and cooling in order to guarantee sustainable utilisation of biomass as early as in 2010. Currently the Commission is developing binding sustainability criteria to be introduced in Europe.

Retrofitting of coal-fired power plants to 100% biomass combustion is gaining in importance all over Europe. The main advantage is the use of existing plant infrastructure adopted to biomass operation and longer operation periods of the plant site. However, economic efficiency of fuel switching is highly
depending on the specific incentive system in each country. Yet it is impos-
sible to operate cost-covering without such incentives. Operators of biomass-
fi red plants are highly interested in using biomass refined by torrefaction,
steam explosion or hydrothermal carbonisation. Refined biomass has a much
higher energy density and can be easier integrated into existing power plant
processes. Several research projects are dealing with the improvement of mar-
et integration and product features of these fuels.

**Decentralised small plants** – fuel cells, micro gas turbines, and Stirling en-
gines can open up new areas of application for combined heat and power
(CHP) generation. These plants are an important technical innovation be-
cause they enable exploiting the benefits of combined generation in very small
ranges of capacity. This applies in particular to applications in local heating
and in the commercial as well as industrial sector. However, these applications
need marketable developments, because economically-efficient plant opera-
tion is always the decisive factor for project realisation.
In 2012, electricity generation from nuclear power was around 2,346 billion kWh worldwide and clearly below the 2011 figure of about 2,500 billion kWh. The decrease in nuclear-based generation is mainly due to the shutdown of Japanese nuclear power plants following the Fukushima event and the political decision in Germany to shut down – first temporarily and then permanently – 8 nuclear power plant units. The share of nuclear power in worldwide electricity generation has been roughly at some 11%. The EU is the leading economic area worldwide in nuclear energy production with about 840 billion kWh.

Since the first commercial nuclear power plant was commissioned in Calder Hall in the United Kingdom in 1956, around 67,950 billion kWh of electricity have been produced on a cumulated basis. This corresponds to about three times the current annual global electricity demand.

The growth of nuclear electricity generation in the 1980s is remarkable. During that time, large power plant projects with unit outputs in excess of 1,000 MW, which had been launched in the 1970s due to the pressure of the first oil price crisis, went into operation and provided considerable generation capacity. Today, the operation of nuclear power plants is characterised by high availability with a worldwide average of nearly 80%.
Currently (state September 2013) 433 nuclear power plants with a total capacity of 387,072 MW are being operated worldwide in 31 countries: another 67 plants are under construction, while roughly 200 plants are being planned or pre-planned to be commissioned by 2030.

Following the Japanese events of March 11, 2011, new built plans were abandoned in Italy and Switzerland only. This does not apply to the plants in e.g. East and South East Europe, Asia, states of the Middle East as well as North and South America. The impact of the current North-American shale-gas boom on local power plant structure as well as plant operation and construction of new nuclear power plants cannot be estimated yet.

Long-term planable perspectives in terms of electricity generation costs and nuclear fuel supply motivate investors to launch new construction programmes.
NUCLEAR IN ENERGY POLICIES AFTER FUKUSHIMA

More than two years after the Fukushima event, the response of the countries which rely on nuclear power can now be evaluated. Firstly it was top priority trying to understand what had happened. We now know that the root cause for the core melting of three reactors and the release of radionuclides in the order of 5 to 10% of the Chernobyl accident had been insufficient design of the site against large tsunamis with wave heights over 10 m on the Sanriku coast, lately 1933, 1896, 1611, and 869.

Second step on all nuclear sites was to check whether comparable deficiencies against all kinds of external hazards might exist. In the EU, Switzerland, and Ukraine, the so-called “stress test” confirmed that no comparable deficiencies existed. Other countries have performed likewise. Furthermore, plant-individual robustness levels were quantified and recommendations for additional accident management measures recommended, where not yet existing.

Third step was and is to install the new systems and procedures where necessary; this process is still ongoing.
In parallel, all 31 countries with nuclear power plants closely scrutinised their future policies on nuclear. Practically all decided to continue with their plans, simply notifying that no reason exists to shut down plants for reasons of safety or precaution.

In addition, several newcomer countries proceeded with their plans to introduce nuclear in their energy mix. Since the Fukushima event, eight countries have in fact started their first new construction projects. Germany is the only country that decided to take its nuclear power plants off the grid.

Abbreviations:
EPR: Generation III+ pressurised water reactor, Areva;
AP1000: Generation III+ pressurised water reactor, Westinghouse;
KERENA: Generation III+ boiling water reactor, Areva;
IAEA: International Atomic Energy Agency

1) Additional accident management measures reduce the risk of radiologically relevant events by more than one order of magnitude.

Sources: IAEA, VGB
Technological development
CO₂ emissions can be reduced gradually through technological development. The average worldwide efficiency increased in recent years from 30 to some 33 % due to the large number of new built projects that were realised. The consequent replacement of old plants with low efficiency (current average worldwide efficiency 33 %) with power plants with high efficiencies of 45 to 50 % would clearly decrease the global amount of CO₂ emissions. Therefore, the gradual reduction of CO₂ emissions by technological development is the first option.
This would result in multiple profit:
- Resource protection,
- Substantial reduction of CO₂ emissions,
- Clear reduction of other emissions, and
- Increased electricity generation from the same fuel amount.
In the long term, electricity could be generated from fossil-sources with only very low CO₂ emissions through capture and subsequent underground storage of CO₂.

Ideas are developed and turn into innovations offering key technologies for future coal-and gas-fired power plants leading to higher efficiencies and environmental and climate protection.
All fossil-fired power plants need higher temperatures and pressures to increase efficiency.
Thus, research and development in all fields of power plant engineering is being carried out. All components of the new power plant generation have to be designed to meet the new requirements, to be tested and need to be fit for permanent operation. This means among others
- Qualification of new materials,
- Proving availability of components and of the entire power plant, and
- Increasing the flexibility of power plant operation.
The way to new power plants starts with component test plants and then via pilot plants to demonstration plants and finally – after having collected sufficient operating experience – to power plants that are ready for the market.
CO₂ reduction potential of coal-fired power plants\(^1\) by increased efficiency

1) Average data for hard coal-fired power plants

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>CO₂ emissions per kWh</th>
<th>CO₂ emissions</th>
<th>Fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>33%</td>
<td>1,015 g CO₂/kWh</td>
<td>436 g coal/kWh</td>
<td>381 g CO₂/kWh</td>
</tr>
<tr>
<td>38%</td>
<td>881 g CO₂/kWh</td>
<td>379 g coal/kWh</td>
<td></td>
</tr>
<tr>
<td>45%</td>
<td>743 g CO₂/kWh</td>
<td>320 g coal/kWh</td>
<td></td>
</tr>
<tr>
<td>43%</td>
<td>669 g CO₂/kWh</td>
<td>288 g coal/kWh</td>
<td></td>
</tr>
</tbody>
</table>

-13% CO₂ reduction

But:
Efficiency loss of 7 to 12% points

CCS: Carbon Capture and Storage. Source: VGB
First generation CCS technology was extensively tested in pilot plants and is now available for use in large-scale demonstration plants. The map provides an overview of CCS projects in Europe.

In spite of funding under the European Economic Programme for Recovery EEPR to 6 CCS demonstration projects and further available funding volume under the EU New Entrants Reserve NER300 from the auctioning of 300 million EU emission unit allowances, no final investment decisions for demonstration plants have been taken yet in Europe. This is due to the public and political resistance towards onshore CO₂ storage and the missing perspective for a long-term business case which is challenged by the currently weak carbon price development. In the USA, Canada, and Australia, CCS demonstration plants for the power sector and other industries are already in operation or under construction. The table shows a selection of international projects.
<table>
<thead>
<tr>
<th>Project</th>
<th>Country</th>
<th>Technology</th>
<th>Fuel</th>
<th>CO₂ capture (Mt/a)</th>
<th>CO₂ transport (km)</th>
<th>CO₂ storage</th>
<th>Start of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snøhvit CO₂ Injection</td>
<td>Norway</td>
<td>Natural gas processing</td>
<td>Natural gas</td>
<td>0.7</td>
<td>152</td>
<td>offshore, SA</td>
<td>2007</td>
</tr>
<tr>
<td>Illinois Industrial CCS Decatur</td>
<td>USA</td>
<td>Ethanol plant, retrofit</td>
<td>Corn</td>
<td>1.0</td>
<td>1.6</td>
<td>onshore, SA</td>
<td>2013</td>
</tr>
<tr>
<td>Kemper County IGCC Project</td>
<td>USA</td>
<td>Power plant, new build</td>
<td>Coal</td>
<td>Pre Co. 3.5</td>
<td>75</td>
<td>onshore, EOR</td>
<td>2014</td>
</tr>
<tr>
<td>Boundary Dam</td>
<td>Canada</td>
<td>Power plant, retrofit</td>
<td>Coal</td>
<td>Post Co. 1.0</td>
<td>100</td>
<td>onshore, EOR, SA</td>
<td>2014</td>
</tr>
<tr>
<td>ACTL</td>
<td>Canada</td>
<td>Fertiliser plant and oil refining</td>
<td>Heavy oil</td>
<td>1.8</td>
<td>240</td>
<td>onshore, EOR</td>
<td>2014</td>
</tr>
<tr>
<td>Quest</td>
<td>Canada</td>
<td>H₂ production</td>
<td>Oil sand, heavy oil</td>
<td>1.2</td>
<td>84</td>
<td>onshore, SA</td>
<td>2015</td>
</tr>
<tr>
<td>Gorgon</td>
<td>Australia</td>
<td>Natural gas processing</td>
<td>Natural gas</td>
<td>3.4 to 4.0</td>
<td>7</td>
<td>onshore, SA</td>
<td>2015</td>
</tr>
<tr>
<td>Rotterdam Opslag en Afvang Demonstratieproject (ROAD)</td>
<td>Netherlands</td>
<td>Power plant, new build</td>
<td>Coal, biomass</td>
<td>Post Co. 1.1</td>
<td>26</td>
<td>offshore, EOR, EGR</td>
<td>?</td>
</tr>
<tr>
<td>Don Valley Power Project</td>
<td>UK</td>
<td>Power plant, new build</td>
<td>Coal</td>
<td>Pre Co. 4.9</td>
<td>400</td>
<td>offshore, SA, EOR</td>
<td>?</td>
</tr>
<tr>
<td>White Rose CCS Project</td>
<td>UK</td>
<td>Power plant, new build</td>
<td>Coal</td>
<td>Oxy 2.0</td>
<td>165</td>
<td>offshore, SA</td>
<td>?</td>
</tr>
<tr>
<td>Peterhead Gas CCS Project</td>
<td>UK</td>
<td>Power plant, retrofit</td>
<td>Natural gas</td>
<td>Post Co. 1.0</td>
<td>102</td>
<td>offshore, EOR, EGR</td>
<td>?</td>
</tr>
</tbody>
</table>

Post Co.: Post combustion, Pre Co.: Pre combustion, Oxy: Oxyfuel
SA: Saline Aquifere, EOR: Enhanced oil recovery, EGR: Enhanced gas recovery

Source: GCCSI
In the next decades, thermal power plants will remain inevitable in order to guarantee uninterrupted secure power supply, because urgently needed and economically efficient secondary energy storages like pumped storage plants, disposing of large capacities in the GWh range, will not be realised due to the intervention in landscape. Besides, the topography of numerous countries prevents the further extension of large storage plants.

Therefore, conventional thermal power plants are still needed for realising increased in-feed of renewables and to maintain the balance between power generation and consumption. Important services (grid stability) are needed, the following has to be provided:

- Back-up capacity that is available any time
- Primary- and secondary control
- Minute reserve and idle power
- Redispatch capacity and black start capacity

The payment schemes for these important tasks assumed by coal- or gas-fired power plants, must also be adopted in order to create an economically sound basis for control operation and to give incentives for investments in new, highly-efficient plants.

Until now, prices at the energy market (generation without major shares of renewables) were determined by the marginal costs of the different types of power plants. Marginal costs means any costs in addition to fixed costs that accrue when a power plant generates power. The width of the coloured bars represents the capacities of one generation technology available on the market. Marginal costs are shown simply by the bar height.

The example depicted results in a market price M1 (€/MWh), which, from an economical point of view, justifies operation of important system-relevant nuclear, lignite-, hard coal-, and gas-fired power plants. If a large amount of renewables-based power is put on the market, the accumulated supply curve is shifted to the right. At equal demand, the market price drops to M2. Gas-fired power plants, formerly in the market and operated economically efficient, are now no longer part of the system.

A system that creates market conditions resulting in low revenues at the wholesale power market due to very high revenues guaranteed to renewables and which pushes aside coal- and gas-fired power plants, which are vital for maintaining system stability, needs to be restructured.
Example for the electricity market price development

Market without feed-in of renewables

Market with feed-in of renewables at fixed prices for renewables.

Demand

Renewables

Capacity bounces from market suffers from reduced operating hours.

Hard coal

Lignite

Nuclear

Oil

Natural gas

GW

M1: Market price without renewables.

M2: Market price with renewables at fixed prices for renewable feed-in.

Source: graphic EnBW, VGB
SYSTEM – RENEWABLES, BACK-UP CAPACITY, FLEXIBILITY AND STORAGE

Suitable technologies (centralised and distributed) are decisive for meeting the targets of energy policies. Such technologies must have a high availability and they must be used optimally. The system, comprising “generation–transmission/distribution–consumption” has to be considered holistically. The parameters efficiency, flexibility, and applicability are being focused. Grid structure and connection to necessary control devices guaranteeing stability and reliability are the main aspects for transmission/distribution technologies. Storage technologies will become more important in order to balance the differences between fluctuating in-feed and controllability of planable generation.

Generation is focused on the efficient use of resources independent of renewables or conventional generation. Flexibility has a new quality in a changing generation portfolio. Conventional power plants and renewables-based generation must permanently meet changing demand and must take into account permanent changes of generation technologies.

Grid control needs permanent supervision to meet consumers demands. The parameters are primary and secondary control, idle power, and inertia of the rotating masses. A stable system, i.e. secure supply, requires provision of certain services and adequate revenues for these services. Based on the requirement that the grid needs to be kept stable at any time, the control instruments of the grid need to be advanced.

A central issue will be which storage technology and to what extend will have to be integrated into the grid. Currently hydro power, i.e. pumped storage plants, are the only mature technology available. New approaches like batteries in connection with e-mobility, adiabatic pressurised storage and “power to gas” have to prove themselves.

Renewables, and this applies in particular to the weather dependent sources wind and solar power, cannot be considered isolatedly. A system approach calls for consideration of all generation options including storage technologies, grid structure, and consumption. A balanced technology mix is the best guarantee for supply security.
Development of storage technologies for electricity is urgently necessary.

System power ratings:
- Metal air batteries
- Flow batteries
- H2 fuel cells
- Pumped hydro
- CAES*
- High energy super capacitors
- NaS battery
- Ni-Cd batteries
- Lead acid batteries
- Li-ion batteries
- Other advanced batteries
- High-power fly wheels
- SMES*

Discharge time at rated power:
- Hours: 1 kW, 10 kW, 100 kW, 1 MW, 10 MW
- Minutes: 100 MW, 1 GW

Representative storage capital cost:
- Capital cost per unit energy (US-$/kWh output) (cost/capacity·efficiency)
  - 10,000
  - 1,000
  - 100
  - 10

Better for UPS & power quality applications
- Better for energy management applications
- Better for long duration applications
- Better for high power applications
- Better for high energy applications
- Better for high energy and high power applications

Source: ESA and Booz & Company analysis

* CAES: Compressed air energy storage, SMES: Superconducting magnetic energy storage
Between 1990 and 2011, the total greenhouse gas emissions (CO₂e) in the European Union (EU-27) decreased by 17%. These figures were given in the latest annual EU report on the inventory of greenhouse gas emissions in the EU.

In accordance with the Kyoto Protocol, the EU (EU-15) is committed to reduce greenhouse gas emissions by 8% for the period 1990 to 2008/2012. The European Council has also set an ambitious target of a 20% reduction by 2020.

In addition, a global approach is needed: to stabilise and reduce CO₂ emissions worldwide, action based on the principle of effectiveness and cost efficiency has to be taken.

Cost-efficient measures such as insulation of buildings, fossil-fired power plants with higher efficiencies, expanded use of renewables at right locations or further use of nuclear energy, etc. must be applied with priority and without prejudice.

The International Energy Agency (IEA) developed a stabilisation concept for achieving a reduction to 14 billion tonnes (BLUE MAP scenario) in comparison to the reference scenario (“Baseline emissions”: 62 billion tonnes CO₂ in 2050).

e: equivalent

CCS provides one-fifth of the lowest-cost GHG reduction solution in 2050.

Reduction options:
- CCS industry and transformation 9%
- CCS power generation 10%
- Nuclear 6%
- Renewables 21%
- Power generation efficiency and fuel switching 7%
- End-use fuel switching 11%
- End-use electricity efficiency 12%
- End-use fuel efficiency 24%

Source: IEA, Technology Roadmap Carbon Capture and Storage
CO₂ emissions total and per capita from fossil fuel combustion for selected regions for 2010 and changes from 2005 to 2010

- **EU-27**: -8% with 3,659 billion t CO₂ per year and 7.29 t CO₂ per capita.
- **India**: +28% with 1,658 billion t CO₂ per year and 1.39 t CO₂ per capita.
- **USA**: -7% with 3,369 billion t CO₂ per year and 17.31 t CO₂ per capita.
- **China**: +19% with 6,40 billion t CO₂ per year and 6.40 t CO₂ per capita.
- **World**: +11% with 30,276 billion t CO₂ per year and 4.44 t CO₂ per capita.

Source: IEA, 2013

CO₂ emissions from different power plants in g CO₂ equivalent per kWh, calculated for the life cycle of the power plant

- **Lignite**
  - 950 to 1,230 g CO₂ equivalent per kWh (BoA technology)
- **Hard coal**
  - 790 to 1,080 g CO₂ equivalent per kWh
- **Oil**
  - 890 g CO₂ equivalent per kWh
- **Natural gas**
  - 640 g CO₂ equivalent per kWh
- **Gas combined cycle**
  - 410 to 430 g CO₂ equivalent per kWh
- **Solar**
  - 35 to 160 g CO₂ equivalent per kWh
- **Nuclear**
  - 16 to 23 g CO₂ equivalent per kWh
- **Wind**
  - 8 to 16 g CO₂ equivalent per kWh
- **Hydro power**
  - 4 to 13 g CO₂ equivalent per kWh

Source: PSI Paul Scherrer Institut, Switzerland, ESU-services, VGB

Result range due to different methods of calculation and different site implications.
VGB PowerTech e.V. is the European technical association for electricity and heat generation with head office located in Essen (Germany). Currently VGB has 511 members, comprising operators, manufacturers, and institutions connected with energy engineering.

Our members come from 36 countries and represent an installed power plant capacity of 530,000 MW, with 471,000 MW located in Europe.

The activities of VGB PowerTech comprise:
- Provision of an international platform for the accumulation, exchange, and transfer of technical know-how.
- Acting as “gate-keeper” and provider of technical know-how for the member companies and other associations of our industry.
- Harmonisation of technical and operational standards.
- Identification and organisation of joint R&D activities.
- Exclusive member access to qualified expert knowledge.
- Representation of members’ interests.

VGB is performing these tasks in close cooperation with EURELECTRIC on European- and the German Bundesverband der Energie- und Wasserwirtschaft (BDEW) on national level as well as further national and international associations.

Structure of the VGB membership:

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil-fired power plants</td>
<td>306,000 MW</td>
</tr>
<tr>
<td>Nuclear power plants</td>
<td>130,000 MW</td>
</tr>
<tr>
<td>Hydro power plants and other renewables</td>
<td>94,000 MW</td>
</tr>
<tr>
<td>Total</td>
<td>530,000 MW</td>
</tr>
</tbody>
</table>

EU: 474 members in 21 countries
- Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, The Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden, United Kingdom

Other Europe: 20 members in 4 countries
- Norway, Russia, Switzerland, Turkey

Outside Europe: 17 members in 11 countries
- Argentina, Australia, Brazil, China, India, Israel, Japan, Libya, Mongolia, South Africa, USA

Total: 511 members in 36 countries
VGB PowerTech e.V. supports its members with all technical issues of electricity and heat generation in order to further optimise:

- Safety
- Efficiency
- Environmental friendliness
- Economic efficiency and
- Occupational safety and health protection

The competence centres “Nuclear Power Plants”, “Power Plant Technologies”, “Renewables and Distributed Generation”, and “Environmental Technology, Chemistry, Safety and Health” are dealing with all aspects of nuclear, conventional and renewable generation. They are cooperating closely to fully exploit the synergies.

The engineering services of the Competence Centre “Technical Services”, the VGB Research Foundation, data bases, and publications perfectly round off the portfolio of expertise of VGB PowerTech.