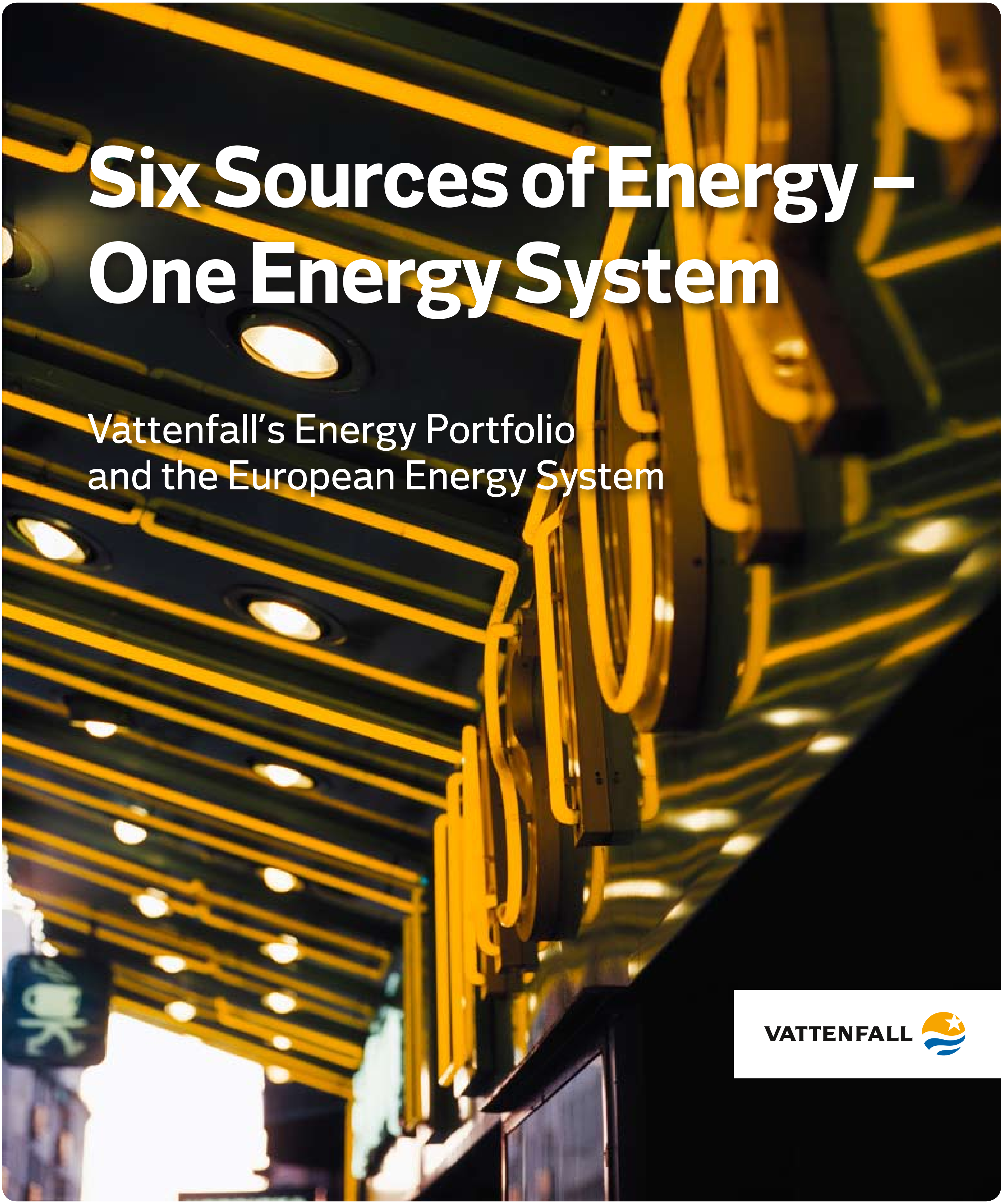
Six Sources of Energy – One Energy System

Vattenfall's Energy Portfolio and the European Energy System



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Coal Power

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COAL POWER

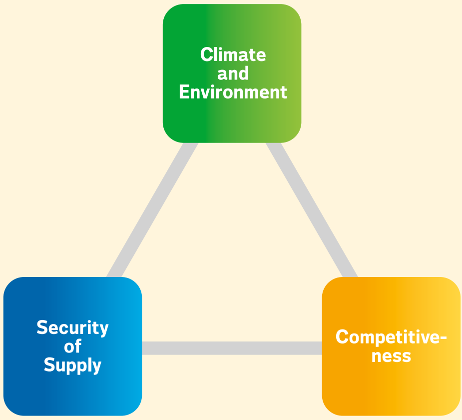
Coal is a cornerstone of the European energy system due to its economic attractiveness and characteristics that allow stable large-scale electricity generation. Coal power accounts for approximately 28 per cent of total electricity generation in the EU. CO_2 released by coal combustion constitutes a large share of global emissions. Carbon Capture and Storage (CCS) is a technology currently under development to reduce CO_2 emissions from coal power plants.

The Energy Triangle – Coal Power

Climate and environment

All energy sources have environmental impact during their life cycles. Combustion of energy sources, particularly fossil fuels, generates CO_2 emissions and contributes to global warming. In the long run, emissions from power production will need to be close to zero if greenhouse gas levels in the atmosphere are to be stabilised.

Coal power plants emit high levels of CO_2 into the atmosphere during the combustion process, which affects the climate. Coal mining also interferes significantly with the landscape, and open-cast mines must be re-cultivated. Major efforts, including the development of clean coal technologies to reduce CO_2 emissions, are being made to manage the climate impact of coal power plants.



Security of supply

Fuel shortages and unreliable electricity systems cause societal and economic problems. Securing supply means guaranteeing that primary energy is available, and that delivered energy is reliable, essentially 100 per cent of the time. This is a major political and technical challenge.

Coal power plants provide stable and large-scale electricity generation, and the availability of coal is good. Of the Earth's fossil fuels, coal is the most abundant and widely dispersed, meaning that supplies are readily available and not subject to disruption.

Competitiveness

Energy is a fundamental input to economic activity, and thus to human welfare and progress. The costs of producing energy vary between different energy sources and technologies. A competitive energy mix will keep overall costs as low as possible given the available resources.

Coal power has a competitive production cost. Fuel costs are low and coal markets are well-functioning. However, technologies to reduce coal power plant CO_2 emissions are expensive and call for substantial investments.

The History of Coal

Coal began forming over 300 million years ago. Of the Earth's fossil fuels, coal is the most abundant. Coal is formed when plants and animal remains are exposed to high pressure in an anaerobic environment over a long period of time, just as in the conversion into oil. There are several different types of coal, two of which are used in electricity generation: lignite and hard coal. Lignite is peat that was converted under high pressure 15 to 20 million years ago. Hard coal is lignite that is exposed to additional pressure deep within the Earth.

An energy source with long history

Humans recognised the advantages of coal early on. Then, as now, coal was considered an efficient, inexpensive energy source. But the use of coal did not truly gain momentum until the industrial revolution.

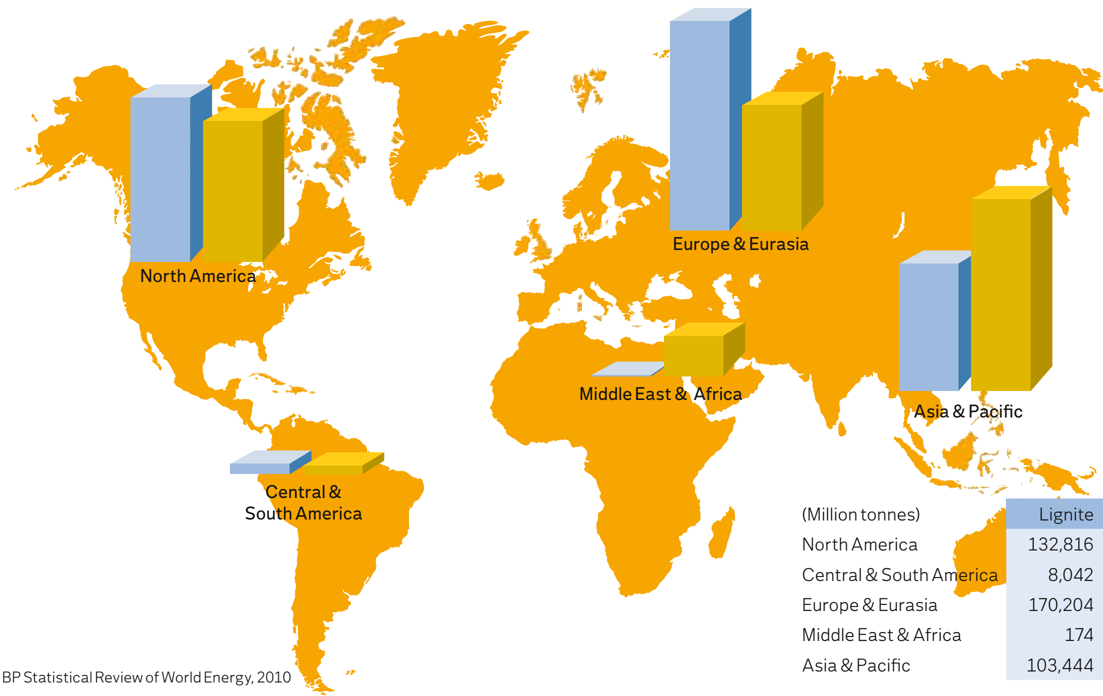
Coal was an important engine of social development during the 18th and 19th centuries, prior to which it was used primarily for heating. In Great Britain large quantities of coal enabled the industrial production of steel to build railways. During the American Civil War, coal was used for iron and steel production. As the industrial revolution spread to the rest of Europe and to Japan, coal's key role was realised.

The use of coal decreased as other more convenient energy sources, such as oil and gas, became increasingly prevalent as fuel and heating sources. Coal was instead used in ways that it is typically used today; for steel manufacturing and electricity generation. Coal remains an important energy source, and has been the fastest growing energy source in terms of volume since the year 2000. Between 1990 and 2008, the amount of coal used in the energy sector increased by almost 50 per cent, and it is expected to continue to grow.[1] The primary reason for this is the increased energy demand in emerging markets such as India and China. Today, coal accounts for more than one-quarter of the world's total energy demand and is therefore one of our most important natural resources.[2]

Coal in many forms

Currently, hard coal and lignite are used primarily in thermal power plants. But the energy contained in coal presents many more possibilities. To begin with, solid coal is converted into liquid or gaseous forms. After gasification or liquefaction coal can be used as a substitute for natural gas or crude oil products. This allows usage in engines, burners or as a base product for the chemical industry.

Global lignite and hard coal reserves (2009)

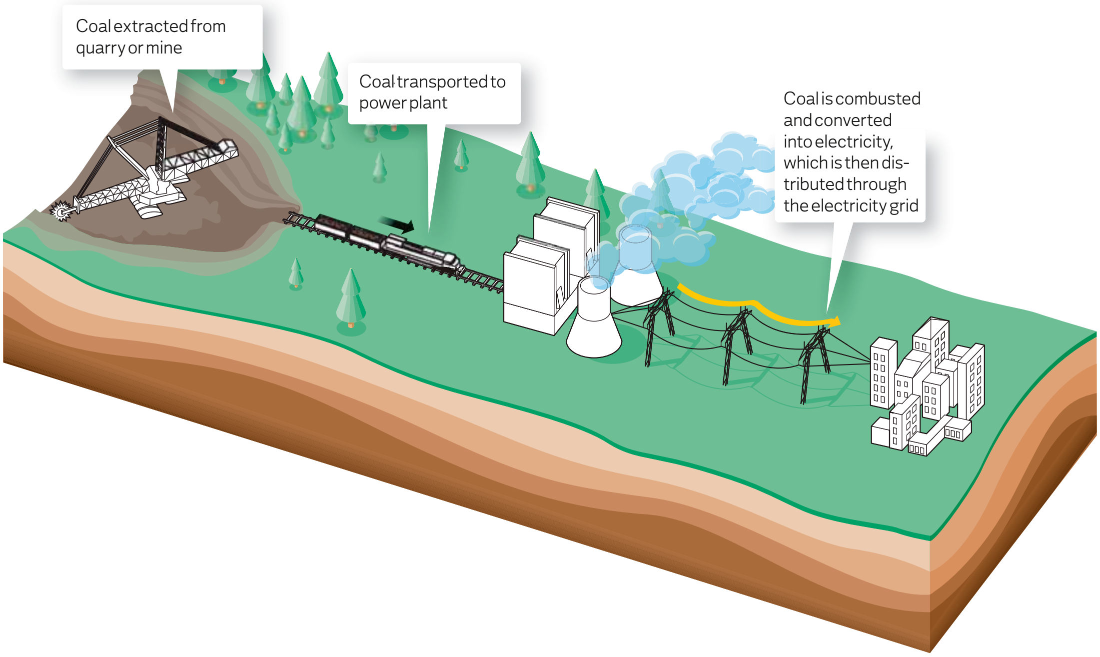


(Million tonnes)	Lignite	Hard Coal
North America	132,816	113,281
Central & South America	8,042	6,964
Europe & Eurasia	170,204	102,042
Middle East & Africa	174	33,225
Asia & Pacific	103,444	155,809

Source: BP Statistical Review of World Energy, 2010

How a Coal-fired Power Plant Works

Coal becomes electricity



Coal becomes electricity

Both types of coal, hard coal and lignite, are used to generate electricity and in some cases district heating. Lignite has lower energy content and is only used in power plants located adjacent to lignite quarries. A hard coal-fired plant is slightly more efficient. But in terms of heat value, lignite is less expensive than hard coal per gigajoule.

In the first coal-fired power plants built at the end of the 19th century, lumps of coal were stoked into simple boilers. Nowadays, coal is usually ground to a fine powder and dried so that it burns hotter and faster. It is then blown into a combustion chamber and burned at a very high temperature. The generated thermal energy heats water, creating steam which is then transferred to a set of turbines that have propeller-like blades. The steam drives the blades, causing a turbine shaft to rotate at high speed. A generator is placed at one end of the turbine shaft. Electricity is produced as the shaft rotates. After passing the turbine, the steam is re-condensed and returned to the boiler to be heated again. In some power plants, the generated heat is also used for district heating.

Coal extraction – how it works

There are two basic methods for extracting coal: underground and opencast mining. The method utilised is based on geology; i.e., the depth of the deposit and the condition of the soil or bedrock around the coal field. Today, underground mining accounts for approximately 60 per cent of global coal production, though this figure varies by area; in Australia, for example, opencast mining accounts for 80 per cent of total coal production.

Surface extraction, from opencast mines, is used in instances where coal lies close to the surface. The coal, mostly lignite, is reached by digging up layers of soil, sand and rock and entails a substantial degree of interference with the landscape and environment. Former mining areas therefore require intensive re-cultivation. Among other things, soil is used to construct lakes, pasturelands or different types of cultivation. Forests, farmland and various biotopes and geotopes are recreated after the landscape is formed.

Underground coal extraction is used when the coal is stored deep in the earth. This type of extraction is more risky than surface mining and therefore requires additional planning measures; for example, advanced drainage and ventilation systems to avoid the accumulation of water or explosive mine damp. Working conditions in coal mines have historically been arduous; even today, some coal mines do not meet modern safety requirements.

Coal technology under constant development

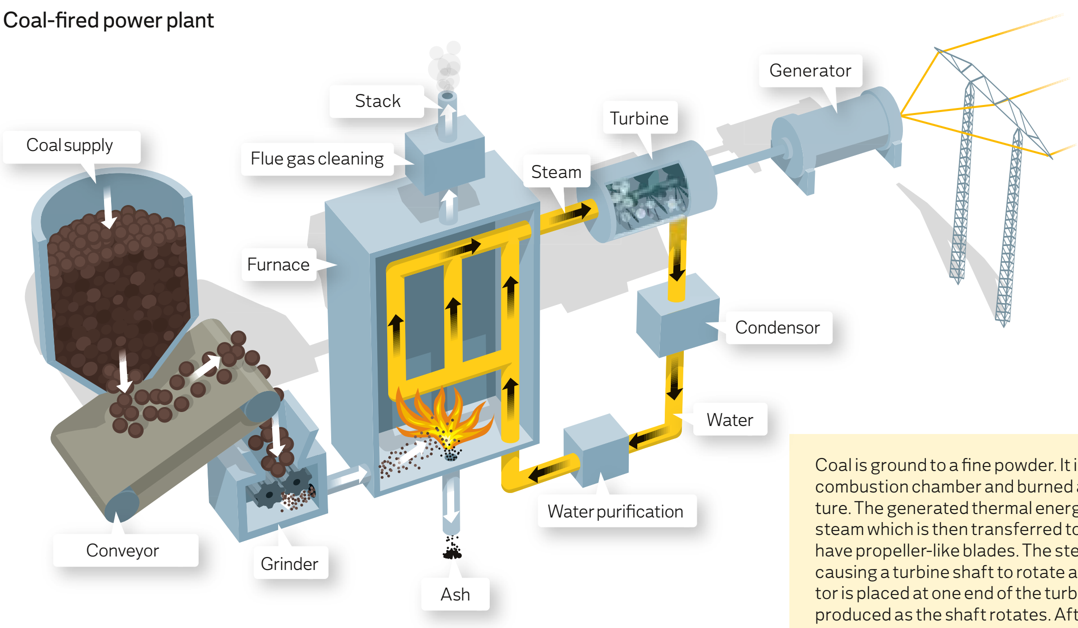
Thanks to new and improved technologies, today's coal-fired power plants are more efficient than ever. Progress has been made in the development of new technologies to reduce emissions over the past 30 to 40 years. Nowadays great quantities of particulates are refined out of the combustion gases that were previously emitted, unfiltered, into the air. Well-developed technologies are able to clean emissions of sulphur, nitrogen oxides, complex hydrocarbons, dust and heavy metals. Flue gas washing, for example, is used to reduce emissions of sulphur. Effective particulate filters can prevent over 99.9 per cent of dust emissions from escaping into the atmosphere.[3]

Coal-fired power plants constructed today are more efficient and emit less CO_2 than older plants. Efficiency is 10 percentage points higher, meaning that less fuel is needed to produce the same amount of energy, while emissions are up to 22 per cent lower. In practice, this means that an efficiency increase of one percentage point reduces CO_2 emissions by two to three per cent.[4]

Today, however, many plants in countries such as China and India are outdated. In 2008 there were over 8,000 small coal-fired power plants in China, many with low efficiency and high emission levels.[5] Most plants in the US, South Africa and Europe need to be replaced as well. The average efficiency of the world's hard coal-fired power plants is currently 28 per cent, compared to more than 46 per cent for modern plants.[6] But in emerging countries, old plants are still needed to meet growing electricity demand.

Despite the fact that emissions of many harmful substances produced by coal combustion can be reduced and eliminated thanks to technological developments, a major problem remains: carbon dioxide. Since the use of coal is expected to increase globally, coal combustion technology for efficiency and emission reduction must make headway. Improved coal combustion efficiency, combined with carbon capture technology, is a prerequisite for decreasing the world's CO_2 emissions.

Coal-fired power plant



Coal is ground to a fine powder. It is then blown into a combustion chamber and burned at a very high temperature. The generated thermal energy heats water, creating steam which is then transferred to a set of turbines that have propeller-like blades. The steam drives the blades, causing a turbine shaft to rotate at high speed. A generator is placed at one end of the turbine shaft. Electricity is produced as the shaft rotates. After passing the turbine, the steam is re-condensed and returned to the boiler to be heated again. In some power plants, the generated heat is also used for district heating.

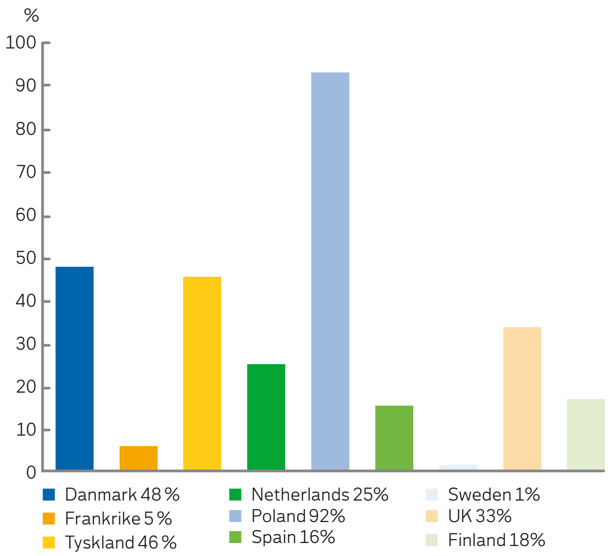
Coal Power in Europe

Many European countries are dependent on coal power to meet their energy needs. In 2008, coal power accounted for 28 per cent of total electricity generation in the EU, down from over 40 per cent in 1990.[7] In absolute terms of measurement, Germany and Poland are the European countries that are most dependent on the use of coal in their electricity generation. In terms of share of energy mix, Denmark and the UK are also major coal users.

In Germany, coal power accounts for approximately 46 per cent of electricity generation. The corresponding figure in Poland is almost 92 per cent.[8] Just as in many other parts of the world, the explanation for coal's significance in these areas is the existence of large domestic coal reserves that are expected to last for a long time, as well as access to reliable, cost-efficient technology for electricity and heat production. This makes coal power a relatively inexpensive energy source that bolsters security of supply in the energy system and increases the degree of energy self-sufficiency. The negative opinion on nuclear power in some European countries also contributes to an increased dependence on coal as a baseload power.

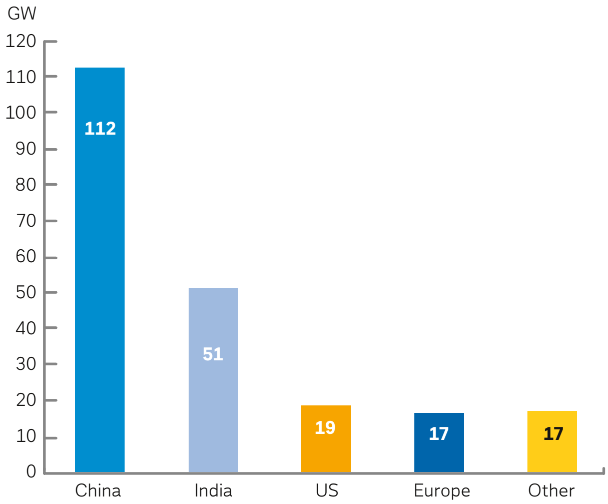
Coal-fired power plants in EU countries have approximately 201 GW of installed capacity, equivalent to roughly 13 per cent of the world's total installed coal power capacity.[9] In growing economies such as China and India, coal power is expanding at a rapid pace. China and India already have a combined installed coal power capacity of 647 GW, more than three times the total EU capacity.[10] In the USA, where half of all electricity generation takes place in coal-fired power plants, total installed capacity amounts to 334 GW.[11]

Share of coal power in electricity generation (2008)



Source: IEA Statistics, Electricity Generation, 2010

Coal-fired power generation capacity under construction (2008)



Source: IEA, World Energy Outlook, 2009

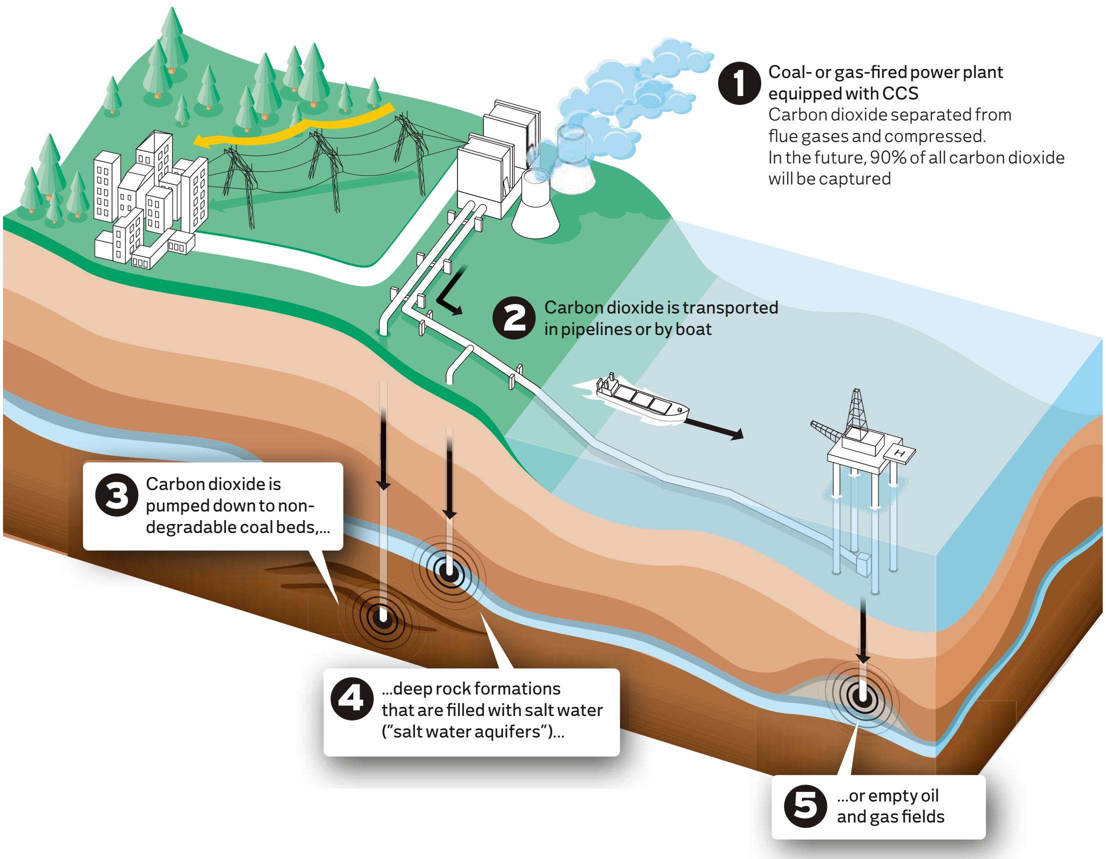
The Future of Coal Power

Coal power will continue to be a cornerstone of the European energy system for the foreseeable future. But carbon dioxide released by coal combustion constitutes a large share of total global emissions. For each produced kilowatt hour of electricity, corresponding roughly to the amount of electricity consumed by watching TV for one evening, modern coal-fired plants emit just under one kilogramme of CO_2. The EU's climate goals call for a 20 per cent reduction in CO_2 emissions over 1990 levels by 2020, so identifying short-term solutions to reduce CO_2 emissions is a key challenge. There is no single solution that can meet this challenge, particularly in light of the fact that many countries currently depend on coal power plants to meet their energy supply needs. A significant expansion of renewable electricity generation is required, as well as continued efforts to develop technology to reduce the climate impact of existing coal-fired power plants. To date, emissions of coal-fired power plants have been significantly reduced through flue gas cleaning and by efficiency measures such as coal drying. But additional measures are needed to minimise CO_2 emissions to the atmosphere. Two important measures are Carbon Capture and Storage technologies and co-firing biomass in coal plants.

Carbon Capture and Storage – underground storage of CO_2

There are currently several projects underway to develop technologies for burning fossil fuel and simultaneously storing the CO_2 released. These methods are known by the collective term CCS (Carbon Capture and Storage). Opinions differ among researchers as to the potential of the technology. At the same time, CCS presents the only technological option to reduce CO_2

Coal- or gas-fired power plant equipped with CCS



emissions in countries that are expected to remain dependant on fossil fuels for the foreseeable future. Within the EU, the development of CCS is considered a prerequisite to achieve the EU's climate goals. According to the IEA's calculations, CO_2 emissions from the energy industry can be reduced by 20 per cent by the year 2050, provided that CCS technology is implemented.[12]

CCS technology is based on separating carbon dioxide from the combustion gases that arise from, for example, fossil fuel power generation. Instead of being emitted into the atmosphere, the CO_2 is separated from other gases and compressed, pumped down and stored in deep geological formations. The storage technology is nothing new; CO_2 injection has long been used within the oil industry, where CO_2 is pumped down into bedrock to extract oil from dwindling reservoirs.

CCS technology – separation, transport and storage

In practice, CCS is a three-phase system: CO_2 separation, transport and storage. Technology for separating CO_2 from other gases has long been used within the industry. Within the agricultural and chemical industries, separated CO_2 is used, for example, to treat pulp or as protective gas in the packaging of food products. CCS technology is the same, albeit with a different purpose: the return of carbon dioxide to deep underground depths.

Power plants are constructed either close to cities that will consume the released heat or close to the fuel source. Neither location necessarily offers geological formations that are suitable for CO_2 storage. The choice of storage site is determined by different criteria; for example, the bedrock's suitability for encapsulating and storing CO_2 for thousands of years. Different countries and regions have different geological conditions, so distances between capture and storage locations will often vary widely. Pipelines and ships are the most attractive options for transporting the large amounts of CO_2 produced in power plants. Large volumes of CO_2 are already transported over long distances in high-pressure pipelines in the US. The pipelines extend over 2,500 km and the transported CO_2 is used to enhance oil production in mature oil fields. Carbon dioxide can also be transported by ship. Existing technology and experience from transporting petroleum gas and natural gas can be transferred to CO_2 transport.

The two most interesting alternatives for storing CO_2 from fossil fuelled power plants are depleted oil and gas reservoirs, and deep saline aquifers. More than 70 enhanced oil recovery (EOR) projects using a similar technology are currently underway throughout the world. Depleted oil and gas fields have proven their capability to hold oil and gas over millions of years and thus have great potential to serve as long-term storage sites for CO_2. Saline aquifers are underground rock formations that contain salty water. Carbon dioxide partially dissolves in the formation water and, in some cases, the CO_2 slowly reacts with minerals to form carbonates, thereby permanently trapping the CO_2 underground.

CCS technology going forward

There is still some way to go before CCS can be used to limit the CO_2 emissions of existing power plants, but the number of demonstration plants is growing rapidly. Provided that research and investments continue, it is estimated that CCS can be operating commercially by around the year 2020.

The majority of today's existing CCS projects focus on storing CO_2 that has been separated at natural gas production facilities or used to increase the production in dwindling oil fields. Research in these areas is focused on verifying the security of the storage site. Other projects include research for higher efficiency within the sequestration process, alternatives for transport and storage and expanding use of commercially available technology.

Provided that research and investments continue, it is estimated that CCS can be operating commercially by around the year 2020.

A number of legal issues must be resolved before large-scale CCS investments can be made. Most of these issues deal with the development of monitoring and security regulations and rules governing liability for accidents and leakage. In the EU, a directive has been passed that should lead to comparable laws for the implementation of CCS in all EU member states.

In almost all cases, preventing CO_2 emissions comes at a price. This is also the case with CCS. One of the major commercial challenges is to reduce energy consumption in the separation process, which essentially lowers the plant's efficiency. Another challenge is to hold down the investment costs of carbon separation technology. Technologies to separate and store CO_2 are most effective in larger coal and heavy oil combustion plants, where the CO_2 concentration is high and the potential amount of separated CO_2 is large enough to justify the use of the technology.

Estimates of future CCS costs vary widely; nearly a decade remains before the technology will be ready for commercial use. Cost estimates will become more concrete as that date approaches. The potential of CCS is obviously closely linked to the cost of utilising the technology. The fact that new technology entails cost is an obstacle faced by all modern energy technology, from wind power to solar cells and sea-wave power.

Co-firing of biomass a way to reduce emissions

Co-firing refers to the use of two or more different types of fuel in a power plant's combustion process. Co-firing of coal and biomass in existing coal-fired power plants has been identified as a cost-effective way to quickly reduce CO_2 emissions, since power plants require relatively few changes to allow for a greater blend of biomass. Biomass is almost entirely carbon neutral, which means that biomass combustion releases approximately the same amount of carbon dioxide as was taken up by the biomass (trees, plants or crops) during its growth. In most power plants, between 10 and 15 per cent of the coal used can be replaced without significant impact on efficiency or increased corrosion risk.[13] Agricultural residue, processed wood fuel and industrial waste can be used as biomass.

Calculations in a recent study show that co-firing at existing coal-fired power plants could increase EU electricity generation from biofuel by 50 to 90 TWh per year, equivalent to 1.5 - 2.5 per cent of the EU's total electricity generation. This could reduce CO_2 emissions by around 85 million tonnes per year, representing an estimated five to 10 per cent of the reductions required to meet the EU 's 2020 climate goal.[14] However, the availability of biomass is limited and there will most likely be competition for the biomass resources that do exist. Future availability depends to a large degree on pricing, on what will be producible at low cost and where it can be produced, and the level of acceptance of biomass production for energy purposes. There is a potential for biomass in European countries, but it is hard to predict the types of biomass that will be used in the future.

Vattenfall and Coal Power

Coal is a cornerstone of the European energy system, due to its economic attractiveness and ability to contribute to secure and stable electricity generation. Vattenfall is optimising its existing production portfolio and investing to enhance efficiency and reduce CO_2 emissions in existing plants. In general, coal will become a smaller part of Vattenfall's portfolio after 2015.

Vattenfall's coal power operations

Vattenfall operates around twenty coal-fired power plants located in Germany, Poland, Denmark and the Netherlands. These plants have an aggregate capacity of about 12 GW and in 2009 accounted for 45 per cent of Vattenfall's electricity generation and 66 per cent of its heat production.

The electricity produced by Vattenfall in Germany is mainly based on lignite. Vattenfall owns and operates its own lignite mines in Lausitz, eastern Germany. Vattenfall is an important employer in that region, and lignite plays a central role for the region's industries and economic development. Vattenfall uses hard coal, purchased from subcontractors, in its hard coal-fired plants in Denmark, Poland, Germany and the Netherlands. In 2009, lignite accounted for a total of 50 TWh and hard coal for a total of 21 TWh of Vattenfall's electricity and heat production. For a full list of Vattenfall's coal power plants, please see the production site at www.vattenfall.com/powerplants.

Vattenfall's coal power operations going forward

Coal power will continue to be a cornerstone of the European energy system for the foreseeable future and, as such, will remain part of Vattenfall's portfolio. Vattenfall is optimising its existing production portfolio and investing to improve efficiency and reduce the CO_2 emissions of existing plants. The Boxberg and Moorburg projects will be completed, and phase two of the Nuon Magnum multi-fuel plant pursued, but no other coal-fired plants will be built until they can be built with CCS.

In general, coal will become a smaller part of Vattenfall's portfolio after 2015, through asset divestment, fuel replacement and switching away from non-commercial plants after 2020.

Strategy to reduce CO_2 exposure

Vattenfall intends to cut its CO_2 exposure from 90 million tonnes in 2010 to 65 million tonnes by 2020. The CO_2-reduction strategy has three legs: divestments, the replacement of hard coal with biomass, and replacement of non-commercial plants. Divestments are expected to reduce CO_2 exposure by 12 to 14 million tonnes per year. Vattenfall has initiated a study exploring options to reduce CO_2 exposure by selling assets, primarily in Poland and Denmark.

Schwarze Pumpe coal power plant in southeast Brandenburg in Germany.

Replacing hard coal with biomass in coal-fired power plants is expected to reduce CO_2 exposure by 8 to 10 million tonnes annually. An extensive biomass programme is underway and has already produced good results.

Lower utilisation rates of older coal-fired plants, and replacement of non-commercial plants with gas, biomass, or CCS when commercially viable. Anticipated reduction of 12 to 14 million tonnes per year.

Due to the completion of the new Moorburg and Boxberg power plants, emissions will increase slightly during the next few years, after which emissions will be gradually reduced through 2020.

Vattenfall's investments in CCS

Vattenfall invests in the development of CCS technology to reduce CO_2 emissions into the atmosphere from coal-fired power plants. Vattenfall is working to integrate CCS in large demonstration plants and is collaborating with various stakeholders to develop the requisite social, legal and financial conditions. An important milestone for Vattenfall's CCS efforts was the construction of a pilot plant at Schwarze Pumpe near Cottbus, Germany, the first of its kind based on lignite. The plant opened on 9 September 2008 and has attracted great international attention and many visits from industry specialists and researchers. The next step is a full-scale demonstration plant of a size sufficient to evaluate commercial conditions at Jänschwalde in Germany. Through Nuon, Vattenfall is also building a pilot plant with pre-combustion technology at the Willem Alexander power plant in Buggenum, Netherlands. Please see Vattenfall's homepage for more information about Vattenfall's CCS projects, www.vattenfall.com/ccs.

Footnotes – Coal power

1 International Energy Agency (IEA), World Energy Outlook 2010
2 Ibid.
3 You can read more about this in Vattenfall's CSR Report 2008
4 IEA, Focus on Clean Coal, 2006
5 OECD, Opportunities and Barriers for Clean Coal and Other Clean Technologies, 2008
6 IEA, 2006, op.cit.
7 IEA, 2010, op.cit.
8 IEA Statistics, Electricity Generation, 2010, www.iea.org
9 IEA, 2010, op. cit
10 Ibid.
11 Ibid.
12 IEA, World Energy Outlook 2009
13 Hansson, J. (2009), Perspectives on Future Bioenergy Use and Trade in a European Policy Context, Chalmers University of Technology, Gothenburg
14 Ibid.

SUMMARY

- **Coal power provides stable and large-scale electricity generation and has a competitive generation cost. Fuel costs are low and coal markets are well-functioning**
- **Many European countries are dependent on coal power to meet their energy needs. In 2008, coal power accounted for 28 per cent of total EU electricity generation**
- **Coal power plants emit high levels of CO_2 into the atmosphere during the combustion process, which affects the climate. Coal mining also interferes significantly with the landscape, and open-cast mines must be re-cultivated**
- **Co-firing of coal and biomass in existing coal-fired power plants has been identified as a cost-effective way to quickly reduce CO_2 emissions. In most power plants, between 10 and 15 per cent of the coal used can be replaced without significant impact on efficiency or increased corrosion risk**
- **Vattenfall operates around twenty coal-fired power plants located in Germany, Poland, Denmark and the Netherlands**
- **Major efforts are being made to manage the climate impact of coal power plants, such as development of clean coal technologies to reduce CO_2 emissions. Vattenfall will not build any new lignite- or hard coal-fired plants until Carbon Capture and Storage (CCS) is a viable technology**
- **Vattenfall will continue to develop CCS technology. Next step is the CCS demonstration plant in Jänschwalde in Germany**
- **Coal power will continue to be a cornerstone of the European energy system for the foreseeable future and, as such, will remain part of Vattenfall's portfolio. Vattenfall is optimising its existing production portfolio and investing to improve efficiency and reduce the CO_2 emissions of existing plants**