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European Sustainable Electricity
Comprehensive Analysis of Future European Demand and
Generation of European Electricity and its Security of Supply

WP3:
Clean coal technologies

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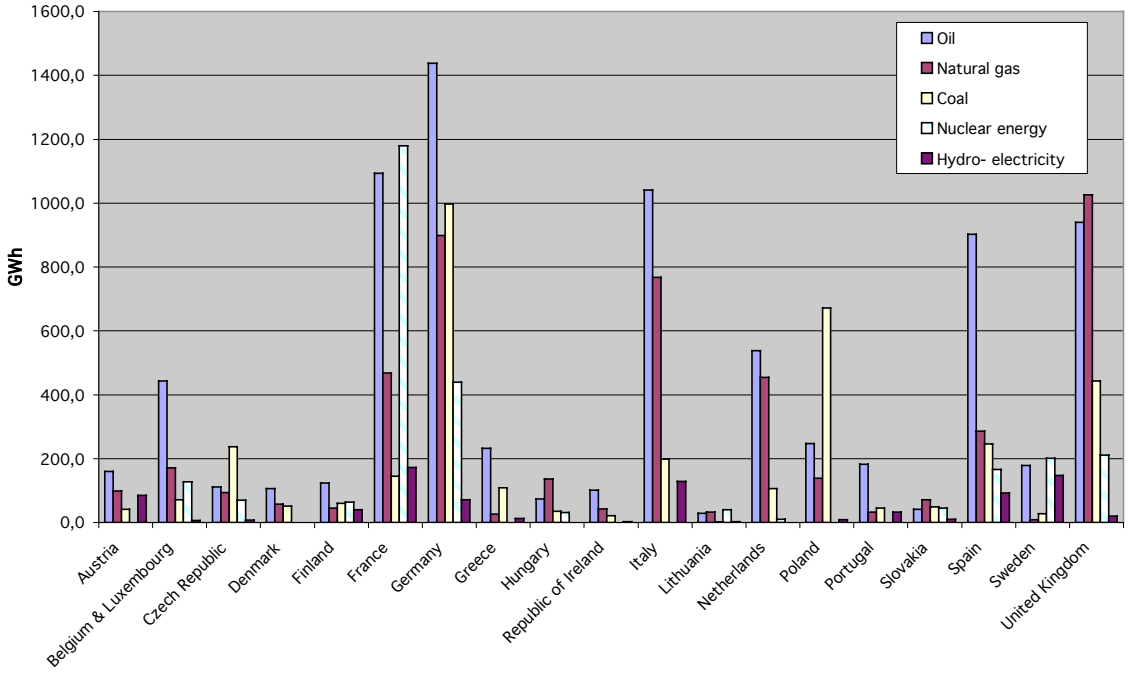
1. Introduction

The fuel of the first industrial revolution is still one of the most important in the beginning of the 21st century. But coal is the fossil fuel that produces the greatest quantity of carbon dioxide by kWh of electricity, one on the greenhouse gas pointed out in all the conferences and studies on global warming. Therefore, clean coal technologies are developed to reduce the emission of CO_2 per unit of energy produced.

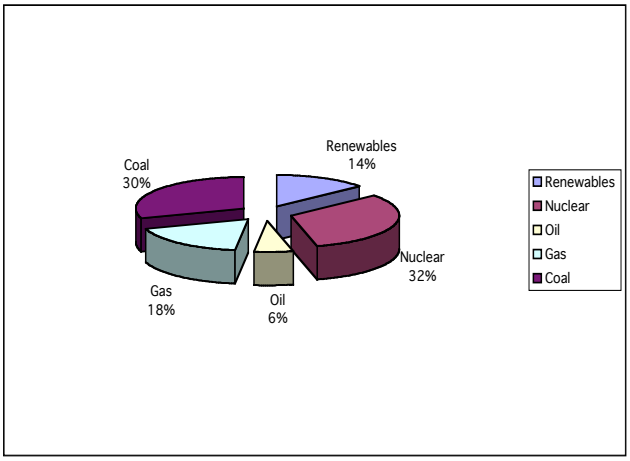


Primary energy consumption in 19 Europeans countries, BP statistical review 2005

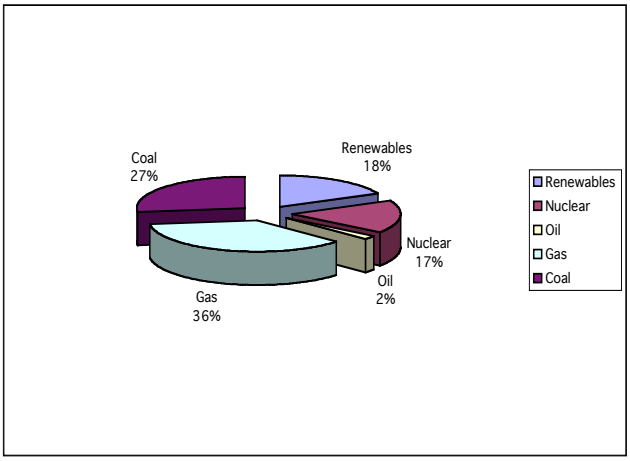
Germany, Poland, United Kingdom and Spain are the biggest consumers of coal in Europe. Coal represents 18% of the European primary energy consumption (41% for oil and 24% for gas). Most of coal is used for electricity production. For example, 48,9% of the electricity in Germany in 2004 (Germany WP1 2005) has been produced with coal. Coal is, in the world, the most important fuel used in electrical power stations, with 39% of the 16054 TWh produced in 2002 (key world energy statistics, IEA 2004).

The number of employees in the coal industry is very large, particularly in two countries: Poland (148 440 employees) and Germany (59 320 employees). About 274 000 people work in the coal industry in Europe (Euracoal across Europe 2005).

As the graph below indicates, even if the share of the electricity produced in the EU-25 with coal will decrease between 2003 and 2030, the quantity of energy produced is expected to increase from 925 TWh in 2003 to 1210 TWh in 2030 (+30%).



Power production (3085 TWh in 2003)



Power production (4478 TWh in 2030)

According to the DGEMP, and shown in the table below, French coal power stations production will decrease till 2010 before it increases afterwards to reach 12600 MW in 2030. They are used for peak demand, mainly in winter. Although production units are mainly nuclear plants, France needs coal stations to adjust the demand of the electric grid.

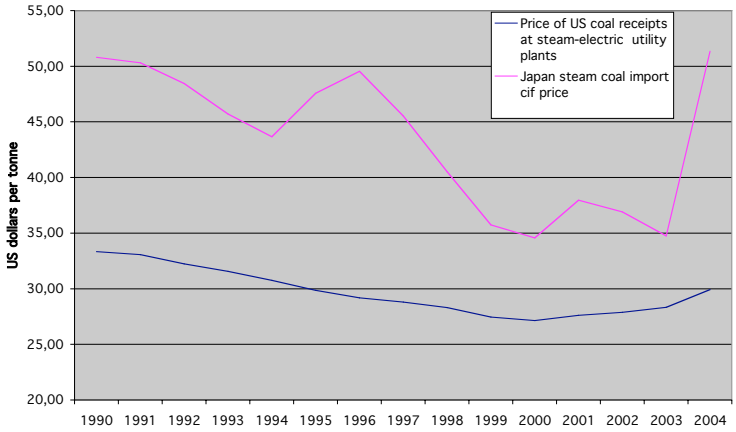
Power installed	2000	2010	2020	2030
Coal	8210 MW	5330 MW	7450 MW	12600 MW

French scenario for electricity production unit based on coal, scenario from DGEMP 2004

Coal reserves are very important and well distributed around the world. This gives a better security supply and stability of prices than oil and gas. But, since two years, coal price has increased a lot, mainly because of an important consumption in China and an increase of fret costs.

	% of the proved reserves	R/P ratio (years)
Europe and Eurasia	32,66	242
Middle East	0,04	399
South and central America	2,19	290
North America	28,99	235
Asia Pacific	31,58	101
Africa	4,54	182
Total	100	192

Proved reserves of coal at the end of 2004, BP statistical review 2005



Prices evolutions in the USA and Japan for electricity production, BP statistical review 2005

2. Clean coal technologies

Because of high emissions of carbon dioxide (global effects), sulphur and ashes (local effects), researches are done, on one hand, to increase the yield of power stations (the easiest way to reduce carbon emissions) and, on the other hand, to capture the pollutants or clean the steam.

The main technology is coal pulverized boiler which is used since the 30's. Research is made to increase the temperature and pressure of the steam.
More recently, **Fluidized-Bed Combustion (FBC)** has been introduced. It can reduce the production of NO_x and fix sulphur using limestone added to coal. Sulphur released from coal in the form of SO_2 is absorbed by limestone, which is injected into the combustion chamber with coal. Around 90% of sulphur can be removed as a solid compound with ashes. FBCs operates at a much lower temperature than conventional pulverized coal boilers. This greatly reduces the amount of NO_x formed. FBC is particularly suited to handle poor quality fuels. This relatively low-cost, clean and efficient technology, although complex to run, could be more widely used in developing countries. There are numbers of different FBC technologies, but the one which is mostly used is known as Circulating Fluidised Bed Combustion (CFBC).

Because reducing local pollution cost some energy, the efficiency of this type of power station will remain below about 40%.

Year of construction	2010	2020	2030	2040	2050
Construction costs (€/kW)	945	918	890	864	838
Efficiency (%)	40	40	40	40	40
Exploitation deadline (years)	30	30	30	40	40
CO_2 emissions (g/kWh)	845	845	845	845	845

Construction duration: 3 years
Project manager costs: 15% of the construction cost
Exploitation cost: 3,5% of the construction cost
Exploitation per kWh: 0,2% of the construction cost
Overheads: 10% of exploitation cost

La prospective technologique des filières non nucléaires
(*technological prospect of non nuclear path*), 2000

Finally, 2 other types of power stations try to use the advantages of combined cycle to the coal stations:

Pressured Fluidized Bed Combustion (PFBC): In this process, coal is burned in a combustion chamber at high pressure (12 – 16 bar) and temperature about 850-900°C with limestone. The relevance of this technology is its compactness of the power station and a yield of about 44%. But there are difficulties to remove dust from hot steam and the gas turbine can be corroded.

Integrated Gasification Combined Cycle (IGCC): IGCC systems involve gasification of coal , usually by high temperature reaction with oxygen, cleaning the gas produced, and burning it in a gas turbine to produce electricity. Part of the residual heat in the exhaust gas of the turbine is used in a heat recovery boiler In the form of steam. This enables to produce additional electricity in a steam turbine generator. IGCC systems are among the cleanest and most efficient of the emerging clean coal technologies: sulphur, nitrogen compounds, and particles are removed before the gas is burned in the gas turbine and thermal efficiencies above 50% are likely to be obtained in the future.

It turns out that the efficiency will increase slowly while construction costs will decrease quickly because the turbine becomes cheaper.

Year of construction	2010	2020	2030	2040	2050
Construction costs (€/kW)	1258	1175	1098	1027	960
Efficiency (%)	45	45	50	50	50
Exploitation deadline (years)	30	40	40	40	40
CO_2 emissions (g/kWh)	750	750	675	675	675

Construction duration: 4 years
Project manager costs: 15% of the construction cost
Exploitation cost: 3,5% of the construction cost
Exploitation per kWh: 0,2% of the construction cost
Overheads: 10% of exploitation cost

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A **cogeneration** plant is an alternative solution. In fact, a simultaneous production of electricity and heat improve the global efficiency of the installation (to about 80%). But it is sometimes difficult to find consumers to use heat because the quantities produced may vary quite a lot during the day and the year. This requires a tricky monitoring.

Another possibility is that of "**polygeneration**" which concerns the gasification of coal. It should be noted that other fuels can be used (biomass, gas or petroleum residues) to produce heat, power and synthetic fuels. Much more poly-generation plants are to be found in the oil than in the coal industry.
Finally, gasification could also be operated *in situ* with Underground Coal Gasification (UCG). In the UCG process, water/steam and air or oxygen are injected into a coal seam. The injected gases react with coal to form a combustible gas which is brought to the surface and cleaned prior to utilization. This relatively new technology is being used to exploit coal seams that are otherwise impossible to mine.
While efficiency improvements and advanced combustion technologies tend to reduce all polluting emissions, the opposite may not be true: the removal of local pollutants has an energy cost and thus tends to slightly increase CO_2 emissions.

3. Coal To Liquid (CTL)

Even if alternative fuels like biofuels, Petrol Gas Liquefied, Natural Gas for Vehicle, are the most used nowadays, other fuels as Gas To Liquid (GTL), Coal To liquid (CTL) and Biomass To Liquid (BTL) are to be developed in the future to compensate the announced decrease of oil production (after the peak oil has been reached) and the constant increasing of oil demand.
Coal To Liquid is an expensive way but the process is known since the 19th century. Germany, during the Second World War, and South Africa, during the apartheid, have used the Fischer-Tropsch process to produce oil from coal. The price is about 40$ per barrel.
This alternative fuel is an attractive solution for the countries with large coal reserves like China and India. With a low cost of coal extraction (about 12$/t), the solution of CTL can be competitive compared to oil. This will be particularly true if the price of the oil barrel becomes sufficiently high (alternative fuel current and future, IFP 2005). Very few researches have been made in this field since the last 20 years and important progress are likely to be possible.

There is only one unit of production, in South Africa, monitored by the South African company, Sasol. Three old units (1955/1982) produce 175000 barrels per day mainly of fuel but also chemical products. The company studies the possibility of two other units of production in China (in the north of Shaanxi and Ningxia).
A project is under construction, located in China with Shenhua (highest coal producer), Its global cost is about 1 billion $ and the commissioning is expected to be by end of 2006 / beginning 2007. A production about 20 000barrels/day (1/3 of petrol, 2/3 of kerosene and diesel) is made using 6000t/day of coal.

The main problem of the production of liquid fuel with coal is the high level of carbon dioxide emitted, more than traditional ways. CO_2 capture and storage can be provide a solution to prevent greenhouse gas emissions at an expenditure of 10 to 20 $/barrel (IFP, 2004)

4. Environment

Coal is the worse fossil fuel which respect to both local and global environment issues. The environmental impacts include those of the mining industry and coal transportation – on the landscape, rivers, ground water and other environmental media.
Coal combustion emits particles, sulphur oxides, nitrogen oxides, mercury and other metals, including some radioactive materials, in a much higher proportion than oil or natural gas. Therefore, it causes local and regional pollution problems (contributing to acid rain and increased ground-level ozone concentrations), and may contribute to global climate change. It has relatively higher emissions of CO_2 than other fossil fuels, as coal's ratio of hydrogen atoms over carbon atoms and power generation efficiency are relatively low compared to other fossil fuels. Coal is also responsible for methane emissions, In particular In mining.
But some studies show that the global CO_2 emissions are coming closer to those of oil, depending upon the technology used. Mining coal but extracting oil or gas and transporting them leads also to quite large emissions of greenhouse gases. For example, gas leaks often occur during Its transport and this has a large impact on environment.

While oil accounts for 36% of total primary energy supply (TPES), against 23% for coal, both fuels are each responsible for 38% each of global energy-related CO_2 emissions. According to recent IEA projections, based on existing energy policies in both the industrialized and developing world, the share of coal in TPES will fall to 22% and coal will be overtaken by natural gas, but its absolute consumption will continue to increase, at least in the next three decades.

Increased use of coal will exacerbate local, regional and global pollution problems unless cleaner and more efficient coal technologies are used. Ultimately, CO_2 capture and storage could be necessary to

reduce global CO_2 emissions. This can be illustrated, for example, by a publication from the US Department of Energy's (EIA 2003). In analyzing the "Climate Stewardship Act", a proposal made by Senators McCain and Lieberman to bring overall US emissions back to 2000 levels by 2025, the EIA foresees a decline in US coal-fired generating capacity from 315 GW in 2001 to 147 GW in 2025. The accepted projects, corresponding to a power of 38 GW (new integrated gasification combined cycle coal plants with carbon capture and sequestration equipment) are far from compensating the shut down of 206 GW. The need to prevent anthropic climate changes will not eliminate the use of coal In the future. However GHG abatement combined with air quality issues will make clean coal technologies essential.

Nevertheless, coal is the energy of the future, just because its stock extends over a few centuries while those of oil and gas are significantly smaller. It will be a key resource to produce synthetic fuels useful and essential in other applications.

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