1. EUSUSTEL WP3 Report on Coal-Fired Technologies

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1.1 Introduction

This chapter should include general and background information about the energy technologies described. The key historical issues and current status of the technology should be mentioned. Introduction should mention the actual technologies included in the study. Maximum 1½ pages.

The demand for energy is growing worldwide – the International Energy Agency (IEA) projects an increase of the energy demand by almost 70% over the next 30 years, with most of that growth taking place in developing countries. To meet this need, the world will have to make the best possible use of the various energy sources available, including coal, the most abundant and affordable of the fossil fuels.

Coal not only makes a key contribution to the energy balance of emerging macro-economies such as those of China and India but is also fundamental to high-developed countries.

For Europe coal, both hard coal and lignite, is an important energy carrier and part of a balanced energy mix. Behind China and the USA, Europe is the region with the coal demand ranking on the third position worldwide. As the electricity demand is anticipated to continue to grow also in Europe, coal is expected to further on play an important role in the energy mix. Even more since the EU expansion the share of coal in energy consumption and especially in the field of electricity production has increased (DEBRIV 2005).

During the last decades pulverized coal combustion under non-critical conditions was and still is the current standard technology for electricity generation from coal. This technology is further developed to be applied under super-critical and ultra-supercritical conditions. This is referred to advanced pulverized coal combustion.

Another promising advanced technology is electricity generation based on coal gasification in Integrated Gasification Combined Cycle (IGCC) power plants.

1.2 General issues on coal-fired technologies

This chapter presents the basic characteristics of the technology.

Coal is the fossil fuel with widest resources world-wide. It currently supplies 23% of global primary energy needs and over 38% of the world's electricity demand. (WCI 2005b) The economies of the two most populous and fastest growing countries in the world today – China and India – are mainly driven by coal-fired electricity. Both countries have substantial domestic coal resources at their disposal and thus possess the basis for a cheap and large scale electricity generation. At global scale however, the demand for individual fossil technologies is not only driven by economic reasons.

For further developed and in particular high-developed countries also other decisive key factors are for instance the need of environmentally sound performance, public acceptance, the use of domestic resources, availability and security of supply of fuels. A further aspect is the issue of network management in order to guarantee sufficient security of electricity supply. In case of ban or limited use of nuclear power there is considerable need for power plant capacities that are able to meet the base load needs of the electricity grid. Facing these aspects fossil fired, in particular coal-fired technologies are currently regarded promising for the installation of new power plant capacity in order to meet the growing electricity demand and the needs for stable and secure electricity generation.

The following chapters give more detailed insight into the technical, economic and environmental performance of coal-fired technologies.

1.2.1 Peculiarities

This subchapter discusses the unique characteristics of the technology, advantages and disadvantages, but not the environmental issues. For PV for example: lightweight semiconductor devise that is easy to mount almost anywhere, Modular structure allows large system size variation, high price, etc. 1-2 pages.

Resource availability

Hard coal and lignite resources are abundant on a global scale. However, for Europe the coal currently extracted within the EU cannot meet the demand in the long term, which is not even possible at present levels. The only European countries with important hard coal resources for economic extraction are Poland and the Czech Republic, but also those will be depleted before the end of this century at current production (BP 2005). Germany has only resources of sub-bituminous coal and lignite, which will likely be depleted in about 30 years at current rate of consumption (BP 2005). Lignite is produced mainly in Germany, Greece, Poland and the Czech Republic, Hungary, Spain and Slovenia (DEBRIV 2005).

Today, South Africa, Australia, South America, and the Russian Federation are the most important coal exporters to Western Europe (GVSt 2004). Large resources are also located in the USA, China, and India (BP 2005). Although hard coal apparently shows advantages for security of supply (lignite is a typical domestic resource), its supply might incur restrictions to some extent, since Australia, South Africa and South America alone will likely not meet future European demand.[1]

According to BP (2005), worldwide proved coal reserves would be depleted in about 170 years at present production levels.

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[1] Coal consumption in Europe in 2004 was nearly 500 Mtoe. Australia, South Africa, and South America produced about 380 Mtoe in year 2004.

Fuel costs

In case of fossil electricity systems, fuel cost is amongst the factors with the highest influence on total electricity production costs. The influence of fuel cost on electricity production costs is about 40% for hard coal steam plants assuming a fuel cost of 56 $/t (BP 2005). The amount, distribution, and transport of fossil resources are important factors for fuel price development.

Estimations for future fuel prices are difficult and quite uncertain. Different scenarios on the development of fossil fuel prices are presented in (EC 2004). The results show the coal price to remain fairly constant until 2030, while there are high fluctuation and increase predicted for oil and gas prices.

1.2.2 Environmental aspects

This subchapter discusses the environmental aspects of the technology; advantages and disadvantages. Primary energy source, toxic building materials, key exhaust materials, energy pay back time, length of the life cycle. 1-2 pages.

Electricity generation from coal had and still has considerable impacts on climate and environment. Although continuous efforts to reducing effluents from coal power plants, especially in advanced economies, by increasing efficiency and installing pollution control devices, coal still remains a polluting power source for its harmful emissions, effluents, and residues.

Reduction of CO_2 and other airborne pollutants from coal-fired power plants are among the main drivers for technology improvement in industrialized countries. Lower CO_2 emissions and mitigation of environmental impacts in general per unit of power supply can be realized with higher plant efficiencies. However, the potential of increasing plant efficiencies is limited by the thermodynamics of the Carnot cycle and the availability of high-strength materials.

In order to reduce the environmental impact of electricity generation from coal, development and application of Clean Coal Technologies (CCTs), designed to realize satisfactorily environmental and economical utilization of coal, is pursued. Further development of CCTs will lead to a number of technology options to minimize the emissions of various undesirable species from coal-fired power plants.

Many of the conventional technologies of today can be further improved or refurbished with effective pollution control technologies. CO_2 capture for sequestration is an extreme option in line with zero-emission strategy that may be implemented for some power plant technologies, including conventional like pulverized coal combustion. CO_2 capture and sequestration technologies are described in a separate report.

There are some main challenges for a sound environmental performance in the electricity generation from coal (WCI 2005b):

1. Increase of the thermal efficiency in order to reduce CO_2 and other emissions per unit of net electricity supplied to the network. The average efficiency of current technologies has been steadily increasing but there is still potential for further improvements.
2. Mitigation or nearly elimination of emissions such as nitrogen oxides, sulphur oxides and particulate matter. This has largely been achieved and costs are decreasing, but this implementation has to be applied to as many units as possible and extended to as many countries as possible, depending on national standards.
3. Mitigation or nearly elimination of CO_2 emissions. The development of so-called 'zero emissions technologies' has been tackled and progressed.

Further development and progress at the numerated points is decisive for a sound environmental performance. The technology, initially installed in coal-fired power plants vitally determines the environmental performance during the whole technical life time, which is about 35 to 40 years for coal-fired units.

The European Commission is currently implementing a "Technology Platform for Zero Emission Fossil Fuel Power Plants" (EC 2005), in order to "identify and remove the obstacles to the creation of highly efficient power plants with near-zero emissions which will drastically reduce the environmental impact of fossil fuel use, particularly coal".[2]

Public research programs are usually developed in collaboration with industry, establishing R&D partnerships like the "AD 700 Power Project" in Europe or the "Canadian Clean Power Coalition" (WCI 2005b). "Zero-emission" power plants are also in the interest of industry at least in industrialized countries, since not only low costs but also a good environmental performance to comply with environmental regulations and reduce external costs are necessary. Therefore, industry is interested in "Clean Coal Technologies (CCT)" in all parts of the coal chain, from extraction and preparation to power plants (WCI 2005a). During a life time of 35 or 40 years

This chapter will be supplemented by information of LCA data concerning energy and material use as well as characteristic terms as primary energy consumption, cumulated energy demand etc.

1.3 Description of coal-fired technologies

This chapter discusses the key technology types included to your topic. Maximum of 3 technologies should be discussed in detail. In addition, advanced/future technologies and future trends should be discussed. The technologies presented at 1.3.1-x should be currently feasible and commercially available. The future technologies (here 1.3.4) should be potential technologies not commercially available, but possible and available by 2030.

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[2] http://europa.eu.int/comm/research/energy/nn/nn_rt/nn_rt_co/article_2268_en.htm (12.9.2005).

The market for large-scale fossil-based power generation technologies is mature. There is a continuous strive to improve environmental performance and reduce costs for existing technologies and to develop competing technologies. (EC 2005)

1.3.1 Pulverized Coal Combustion /(Condensing)

This subchapter discusses your first technology type in detail. That includes advantages and limits; environmental issues;and technical and material issues. 3-10 pages per thechnology.

1.3.1.1 Technology description and characteristics

A major power generation technology is Pulverised Combustion (PC). Combustion of coal in pulverized form has been developed and applied for more than 60 years with continuous improvements in design and performance. Today the technology of Pulverised Coal Combustion is used worldwide for power generation both in developed and developing nations. Thousands of units exist, accounting for well over 90% of total coal-fired capacity and 40% of the total electricity produced worldwide (IEA Clean Coal 2005a; WCI 2005a, IEA 2003). Pulverized coal combustion is considered as mature technology, which is completely proven and commercially available. It features excellent availability properties and is able to be applied for a wide range of internationally traded coals (EC 2001).

For operation coal is crushed and milled to a fine powder, containing particles between 5 and 400 µm in diameter. For bituminous coal 70-75% of the particles feature sizes smaller than 75 µm, only 2% have a diameter larger than 300 µm (IEA Clean Coal 2005a). Together with part of the combustion air this pulverised coal is blown through the burners into the boiler. Secondary and tertiary air is also added either in the burners or directly in the combustion chamber. In the burners the coal powder is combusted at temperatures ranging 1500-1700°C with bituminous coal and 1300-1600°C with lower rank coals (IEA Clean Coal 2005a).

The heat generated in the boiler is transferred through a heat exchanger and used to produce superheated steam. Following this high-temperature and high-pressure steam is expanded in a steam turbine coupled with a power generator.

Pulverized coal combustion as described in this chapter (1.3.1) is state of the art. Further landmarks in improving this technology are the supercritical, the ultra-supercritical and the pressurised versions of pulverized coal combustion, requiring further R&D. The development and deployment of super-critical and ultra-supercritical pulverized coal combustion is described in chapter 1.3.2.

The layout of a pulverized coal combustion plant is pictured in figure 1.

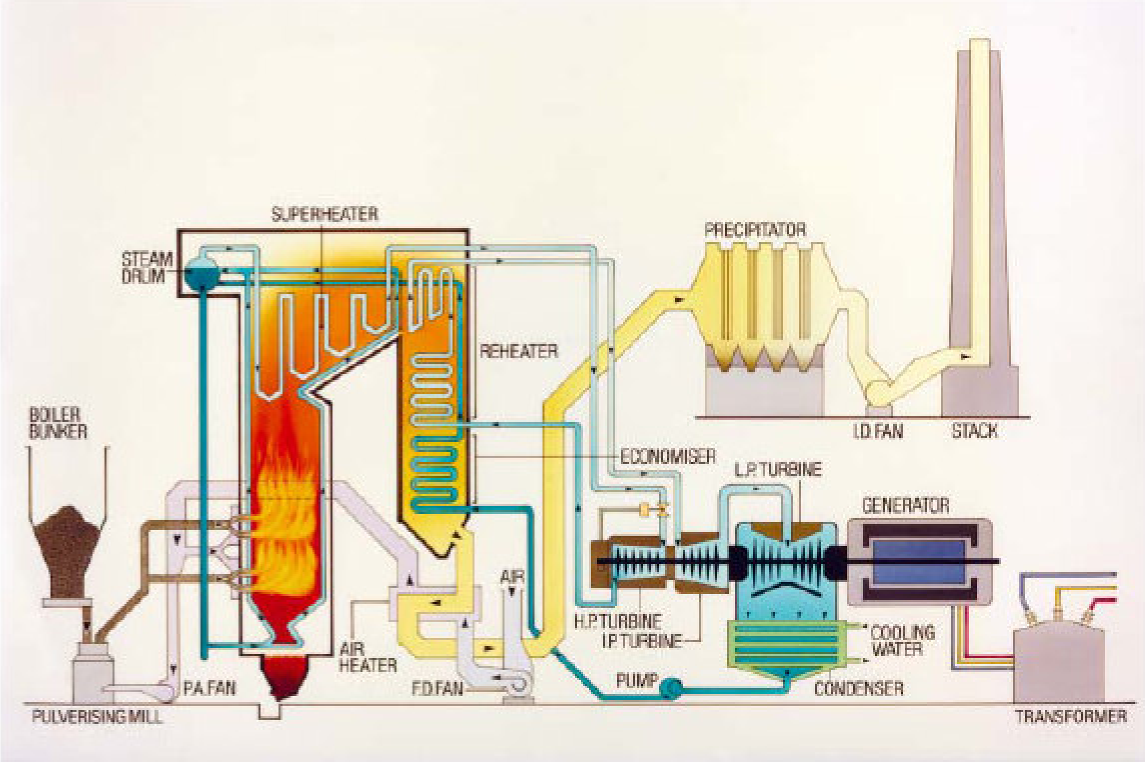

Figure 1: Layout of a pulverized coal combustion power plant (IEA 2003)

1.3.1.1.1 Burner

Different configurations of the burners in the combustion chamber are possible (IEA Clean Coal 2005a). There are three main designs for burners in a combustion chamber:

- wall-mounted burners on one side
- opposed-fired wall mounted burners
- tangential burners in the corners or on the walls

The choice of burners is mostly is based on cost factors, operating experience, environmental constraints and manufacturer's experience (IEA Clean Coal 2005a). Additional important parameters are also the capacity of the boiler and the requirements to turn-down ration.

As further concept downshot burners are used that send the coal-air mixture down into the cone at the base of the boiler. This burner-concept is commonly applied in boilers which use anthracite as the fuel (IEA Clean Coal 2005a). It has the characteristic to achieve longer residence times and thus ensure a more thorough carbon burn-out.

Another arrangement used in some boilers is the so-called cell burner. This involves a wall-fired unit where either two or three circular burners are combined into a single vertically orientated assembly that results in a compact intense flame. This would generally not be used in new units, as the higher temperature flame results in more NOx formation which then has to be removed later in the system (IEA Clean Coal 2005a)

1.3.1.1.2 Boiler

There are two broadly different boiler designs that are mainly used for pulverized coal combustion. One is the two-pass layout made of a furnace chamber topped by the heat exchanger for superheating the steam. The flue gases coming from the combustion chamber change direction by 180° and pass downwards through the main heat transfer and economiser sections.

The other type is a tower boiler with the combustion chamber at the bottom and nearly all the heat transfer sections stacked vertically above each other. Both tower designs are commercially applied and diffused in Europe. In Japan, due to earthquakes, the two-pas layout is preferred because of the smaller height. (IEA Clean Coal 2005a).

Conventional pulverized combustion units operate at nearly atmospheric pressure, thus simplifying the material flows through the plant (IEA Clean Coal 2005a)

Boilers are normally operated at the minimum practicable excess air amount. On the one hand sufficient air is required to burn virtually all the carbon present (99%+), on the other hand the addition of air has to be controlled and staged in order to minimise the formation of NOx (air staging) (IEA Clean Coal 2005a).

Particle residence time in the boiler is typically 2-5 seconds. Facing this short time smaller sizes (i.e. higher ratio surface to volume) favour complete combustion (IEA Clean Coal 2005a).

The solid residues from the combustion consist of 80-90% of fine fly ash with a low level of carbon-in-ash, averaging around 0.5%. Most of the ash passes out with the flue gases as fine solid particles to be collected in electrostatic precipitators (ESPs) or fabric filters before the stack (IEA Clean Coal 2005a).

1.3.1.2 Present market of pulverized coal combustion and technology use

Pulverized combustion power plant units generally range between 50 and 1300 MWe (IEA Clean Coal 2005a). Most new pulverized combustion units are rated at over 300 MWe, because the performance increases and costs decrease with economies of scale. However, only a few large units with outputs from a single boiler/turbine combination of more than 700 MWe exist, which are suitable only in relatively large and relatively dense power grids (IEA Clean Coal 2005a).

The overall thermal efficiency of some older, relatively small units can be as low as 30% or even slightly lower (IEA Clean Coal 2005a). In small units, the net efficiency can be further penalized by the high ratio of auxiliary power. An average thermal efficiency of 35%-36% (Lower Heating Value – LHV - basis) is commonly assumed for larger existing plants with sub-critical steam conditions and relatively high quality coals as feedstock (IEA Clean Coal 2005a, IEA 2003).

New conventional pulverized combustion power plants achieve up to 41% efficiency when burning high quality coal and being used for base-load, thus working at optimum level (EC 2003). Lignite-fired pulverized combustion power plants are operated for base load, but feature lower efficiencies because of the lower heating value of lignite. Most hard coal-fired units work at load follow (intermediate load) and thus operate a considerable proportion of their time below maximum output.

According to (CCTP 2003), the efficiency of supercritical pulverized combustion power plants is less affected by part-load operation than subcritical plants. For example, available data suggest reductions in plant efficiency for supercritical units of around 2% at 75% load compared with 4% reduction for a subcritical plant under comparable conditions.

Further efficiency increase is achievable by decreasing ambient temperatures of the pulverized combustion power plants. Units operate more efficiently with colder air temperatures, and with lower temperature cooling water (IEA Clean Coal 2005a). The cooling conditions going from near-river cooling tower to direct sea water cooling operation make a gain in efficiency of about 2 point percent.

1.3.1.3 Future technological improvements and developments of coal-fired pulverized coal-combustion

Further increase of the thermal efficiency relative to current design and practice are pursued by several measures and technological improvements. However, it is important to take into account that the implementation of the following points listed is always subject to a trade-off analysis between costs (both capital and operating), the risk element in the decision and the energy recovered (IEA Clean Coal 2005a).

- reduction of the excess air ratio from 25% to 15% is expected to give a small efficiency increase
- reduction of the stack gas exit temperature by 10°K (while recovering the heat involved) can bring about a similar increase
- increase of the steam pressure and the temperature from 25 MPa/540°C to 30 MPa/600°C can increase efficiency by nearly 2%
- using a second reheat stage can add another 1%
- decreasing the condenser pressure, exemplarily from 0.0065 MPa to 0.003 MPa, can further increase efficiency.

Some of these technical improvement have already been developed and conceptualized in the 1950s and 60s, but were abandoned either because of the lack of suitable construction materials or the low energy prices prevailing. This removed much of the incentive for seeking high thermal efficiencies. Base-load power plants using steam at 35 MPa and 650°C were already built in the 1950s, which were small compared to sizes realized today, yet at the limits of available technology by that time.

Regenerative preheating of the feed water was introduced as long ago as the 1920s. Steam reheat was introduced in the 1950s and double reheat in the 60s. The more costly options tended to be discounted when oil was cheap, and subsequently as nuclear energy took over base load power generation in many places (IEA Clean Coal 2005a).

Load chance flexibility is challenging task for coal-fired power plants, which is permanently under focus and continually improved in order to ensure that units can load follow satisfactorily.

Emissions limits and environmental requirements are a further driver for technological improvements. Flue gas cleaning units are installed and further improved in order to achieve an environmental performance according to the requirements. Efficiency improvements generally go in line with a reduction of negative environmental impacts. Increased efficiencies entail a reduced feedstock input and mitigate the emissions released during the process of electricity generation, for instance the amounts of greenhouse gases per energy unit. At the same time resources are more efficiently used, which also results in better economics. Cost saving can also be realized by technical components, which can be smaller dimensioned and more economically designed as a result of efficiency improvements.

Generally, few developments are expected for sub critical and supercritical PRC, as ultra-supercritical pulverized coal combustion is considered to be more promising (chapter 1.3.2). Efficiencies higher than 50% are expected for ultra-supercritical around 2010-2015. (EC 2005)

1.3.2 Advanced Pulverized Coal Combustion (APCC)

This subchapter discusses your second technology type in detail, if a second technology is needed. Otherwise it should be removed.

Over the years, pulverized coal combustion was improved by continually development in order to realize an increased thermal efficiency, enhance the environmental performance, improve the availability and reduce the costs of electricity generation. The improvement to the so called advanced pulverized coal combustion is characterised by power plants with super-critical and ultra-supercritical conditions. Hereby the thermal efficiency is increased by rising steam pressure and temperature at the boiler outlet/steam turbine inlet.

1.3.2.1 Technology description and characteristics

Higher efficiencies in pulverized coal combustion can be achieved by increasing the temperature difference across the steam turbine. This is reached by using higher steam temperatures. Furthermore a pressure increase results in a higher efficiency. When the pressure exceeds 221, the fluid is termed supercritical (DTI 2001).
In the 1950s and 1960s a few supercritical plant with extremely high steam conditions had been built in the UK and the USA. However without the benefits of today’s materials, these power plants featured a low availability and couldn’t penetrate the market (DTI 2001).

Not until the development of new materials took place in the following decades, the introduction of boilers for pulverized coal combustion with high availability at supercritical conditions was facilitated, which means boilers capable of operating at steam conditions up to 300 bar, 600°C/620°C (DTI 2001). For the operation of ultra-supercritical plants (pressures >248 bar and temperatures >566°C and as high as 700°C) resistant materials are required and still under further development (WCI 2005a, IEA Clean Coal 2005a). Advanced materials, e.g. new high temperature alloys, are used for the boiler (water walls/evaporators, steam separating vessels, superheater tubes, steam pipes) and the steam turbine (CCTP 2002). Nowadays, steam conditions up to 300 bar/600°C/620°C are achievable. The use of nickel-based alloys is expected to permit 350 bar/700°C/720°C (Bernero 2002). CCTP (2002) further shows an increase of steam parameters up to 370 bar/700°C/720°C, which is pictured in Figure 2. Together with other optimization measures, this would allow net efficiencies of about 50% for power plants with good cooling conditions, e.g. seawater-cooled power plants (Bernero 2002, CCTP 2002). A demonstration plant (capacity 400-1000 MW) within the joint European project “Advanced (700°C) PCC Power Plant” is planned to be in operation by 2010. (Bernero 2002).

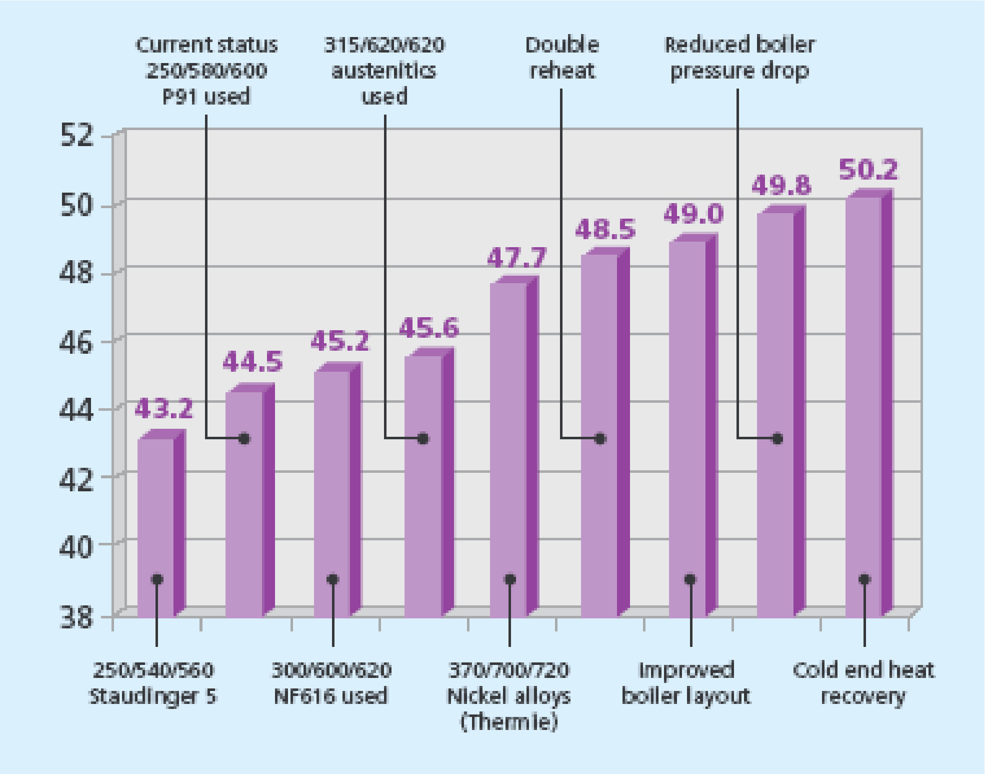

Figure 2 **Likely increase of net efficiency, with reference to a currently operational power plant in Germany (Staudinger V), due to use of advanced materials and improved plant design (CCTP 2002).**

Supercritical power plants show favourable operating conditions. The once-through boiler design features operational flexibility allowing increased load change rates. Average availabilities of 85% and for some units with appropriate design and material availabilities of higher than 90% have been observed (DTI 2001). In general there is no loss of flexibility in moving from sub-critical to super-critical conditions.

A general advantage of supercritical PC units is the good part-load performance, which is superior to that of other advanced technologies for electricity generation from coal, as for instance IGCC technology (Bernero 2002).

The state of the art in the field of lignite-fired pulverized combustion is currently installed in Germany (Breuer, Altmann 2005). During the last years Vattenfall Europe has commissioned some lignite-fired power plants with super-critical steam conditions. Further power plants are at planning stage. Three of the recently installed lignite pulverized combustion plants revealed very positive in the continuous operation so far. Table summarizes the technical characteristics and the experiences obtained from these power plants so far.

Power plant	efficiency		thermodynamic parameters	
	projected	measured	pressure	temperature
Schwarze Pumpe	40,5 %	41,1 %	262 bar; 35/46 mbar	547/565°C
Boxberg	41,7 %	42,7 %	266 bar; 41mbar	545/581°C
Lippendorf	42,3 %	42,8 %	267 bar; 38 mbar	554/583°C

table 1 technical characteristic of lignite-fired pulverized combustion power plants with super-critical conditions in Germany (Breuer, Altmann 2005).

For lignite-fired pulverized combustion plants with super-critical conditions that currently are at planning stage or under construction, further efficiency increases up to 45% are expected. (Breuer, Altmann 2005). This is realized by optimizations within the facilities and further elevation of thermodynamic parameters.

The time from the planning start of a lignite-fired power plant until begin of continuous operation is presently experienced to be about 70 month (Breuer, Altmann 2005).

1.3.2.1.1 Flue gas cleaning/emissions and residues

Reduce of the most emissions species produced by coal combustion in pulverized combustion is realized through post-combustion pollution control devices. Electrostatic precipitators (ESPs) and/or fabric filters can remove more than 99% of fly ash from flue gases, as discussed above. Flue gas desulphurisation (FGD) plants can remove 90-97% of sulphur oxides (SO_x) from flue gases, and convert it into gypsum for use in buildings (WCI 2005a). Selective catalytic NO_x reduction, a post-combustion technique, can achieve reductions of 80-90% (WCI 2005a). NO_x can also be controlled using low-NO_x burners, effective up to 40%, and reburning techniques (WCI 2005a). Together these two techniques reduce NO_x emissions up to 70% (WCI 2005a).

Emissions from advanced pulverized combustion units with appropriate, well-proven technology ESP, de-SO_x and de-NO_x flue gas cleaning plants can meet all current emission standards reliably and economically, although the capital cost can represent about one third of the cost of the unit when meeting the most stringent current standards (IEA Clean Coal 2005a). The operation of these emission control measures has a relatively small effect on overall thermal efficiency (IEA Clean Coal 2005a).

Most pulverized combustion boilers operate with a dry bottom, which produces coarse bottom ash (IEA Clean Coal 2005a); the other boiler type uses wet bottom, which produces boiler slags. Most of the ash (65%-85% (Pflughoeft-Hassett, Hassett, Schroeder 1999)) is transported out of the boiler by the flue gases as fine solid particles, to be collected in ESPs or fabric filters and thus removed from the exhaust before it is released through the stack. The solid residues from coal combustion in PCs consist of 80-90% of fine fly ash with a low level of carbon-in-ash, averaging around 0.5% (IEA Clean Coal 2005a). Boilers with cyclone burners use coarser coal feed (95% is <1/4 in. (Pflughoeft-

Hassett, Hassett, Schroeder 1999)), and shall be considered separately from pulverized combustion. They produce much higher bottom ash than pulverized combustion, up to 75%-90% depending on coal quality, and smaller amounts of fly ash (Pflughoeft-Hassett, Hassett, Schroeder 1999).

1.3.1.2 Present market of Advanced Pulverized Coal Combustion (APCC) and technology use

Pulverized Combustion units using steam in supercritical conditions has already become the norm for new installations in industrialised countries (PF 03-05 2003). Between 1995 and 1999 in OECD countries 19,4GW_e of super-critical coal-fired power plant capacity was commissioned compared with just 3,0 GW_e of sub-critical capacity (DTI 2001).

Capital costs of supercritical PCs are slightly higher than those of conventional PCs; the costs per used unit of coal are significantly lower than PCs because of the increased efficiency and, in many cases, higher plant availability (WCI 2005b). As due to the higher efficiency less coal is needed, supercritical and ultra-supercritical power plants show considerable savings in energy costs, which usually account for 60-80% of the total operating costs,. For a typical power plant case, a cost saving of 17% has been calculated (DTI 2001).

More than 400 plants are in operation worldwide, some of them in developing countries (WCI 2005b). Modern installed plants with elevated steam temperatures and pressures can achieve overall thermal efficiencies in the 43-45% range, depending on location (IEA Clean Coal 2005a; WCI 2005a). Net efficiencies of 45-47% are achievable with supercritical steam using bituminous coals and currently developed materials (IEA Clean Coal 2005a).

An electric net efficiency of 43% is documented for the hard coal power plants Staudinger V near Hamburg and in Rostock, Germany. These plants have net capacities of 509 MW, steam pressure of 26.2 MPa, and steam temperatures of 545°C/562°C (Schuknecht 2003). The hard coal plant Nordjylland 3 in Denmark with a capacity of 400 MW shows the currently highest net efficiency in Europe, 47%. Steam parameters are 290 bar/582°C/580°C (Bernero 2002). One of the most advanced lignite power plants of today is the unit Niederaussem K with a capacity of 950 MW, a net efficiency of 45.2% and steam parameters are 275 bar/580°C/600°C (Jordal et al. 2004).

Starting from current average efficiency of 47% for hard coal APCC an efficiency increase of 5 percentage points to 52% is expected from the year 2015 onwards (EU 2005). This efficiency enhancement together with further R&D in emission control devices will reduce the specific emissions from currently 201 g CO_2/kWh_{el} and 0,6 g SO_2/kWh_{el} to 181 g CO_2/kWh_{el} respectively 0,53 g SO_2/kWh_{el} in the year 2015. (EU 2005). The maximum efficiencies achievable with lower grade and lower rank coals are somewhat lower than the cited efficiency with burning high quality coal. Long-term research is ongoing to achieve, with advanced steam conditions for supercritical and ultra-supercritical PC cycles, thermal efficiencies of 50% (IEA Clean Coal 2005a) and over 50% (PF 03-05 2003). Efficiencies higher than 50% are expected for ultra-supercritical around 2010-2015. (EC 2005). As further developments especially the development of new advanced materials, including superalloys, take place efficiencies up to 55% for hard coal APCC may ultimately be achieved (IEA 2003, WCI 2005a))

1.3.1.3 Future technological improvements and developments of Advanced Pulverized Coal Combustion (APCC)

The efficiency of a pulverized combustion power plant is mainly determined by the efficiencies of the steam cycle and the boiler implying the application of higher steam temperatures and pressures (EC 2005). Few developments are expected for sub-critical and super-critical pulverized combustion, as ultra-supercritical pulverized combustionis considered being more promising. Thus future development of super-critical boiler technology will be focused mainly on increasing steam conditions to achieve higher cycle efficiency (DTI 2001). This will require changes to the traditional alloys used for boiler construction and most components. Under special focus is the development of new nickel based alloys and the improvement of the manufacturability of the alloys (EC 2005). The European ‘THERMIE 700’ project aims at the development of high-nickel alloys required for superheaters and steam pipework. In the project COMTES 700 plant operation at 700°C is investigated at an existing hard coal-fired 750 MW power plant and components as heating surface sections, thick-walled components, piping and fittings are tested (EURACOAL 2005). From these components of a critical power plant also experience on steam oxidation, expansion and flue gas corrosion will be gained

The potential for efficiency improvements of supercritical PC power plants remains substantial. Figure 2 shows the possible increases of net efficiency up to more than 50% starting from an actual German power plant with 43% (Staudinger V), by optimizing plant design and using advanced materials in order to increase steam parameters. A possible road map for pulverized coal combustion is pictured in Figure 3.

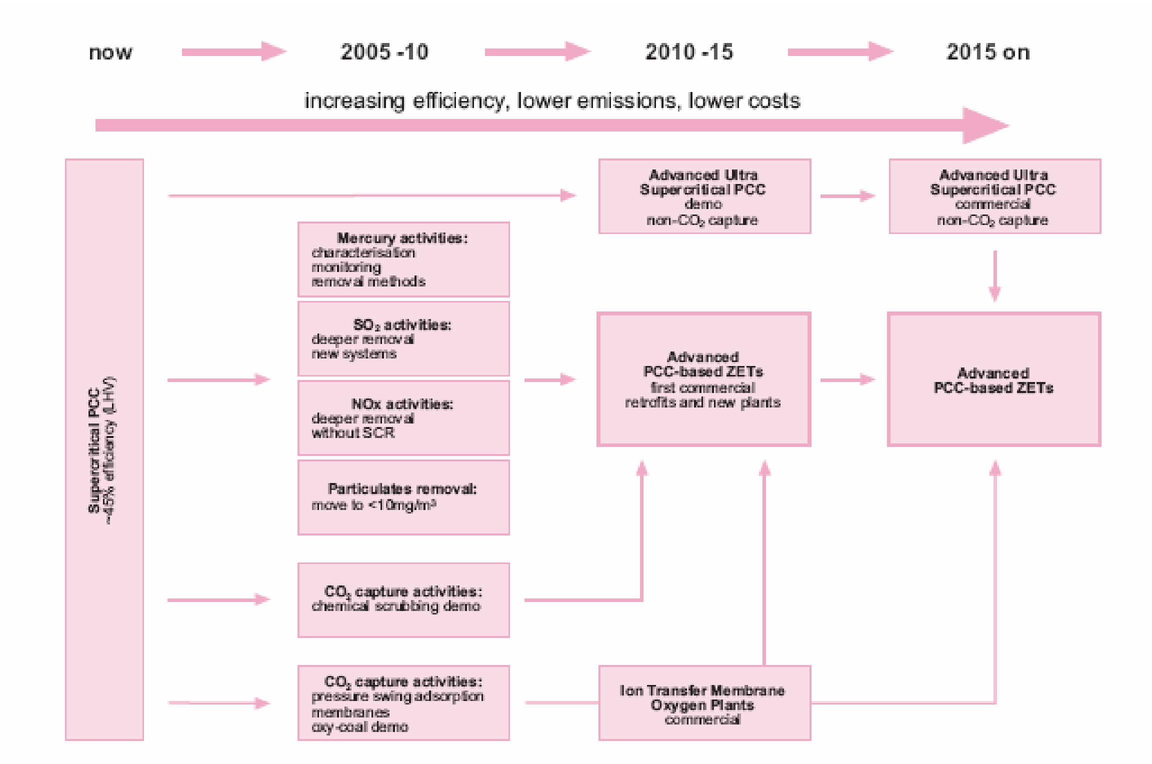

Figure 3 **Roadmapping the future of pulverized coal combustion technology (IEA 2005).**

Schuknecht (2003) estimates a similar potential in his calculations resulting in an increase in efficiency from 44.7% of the reference plant up to 51.1% (LHV) by increasing the efficiencies of single components, steam parameters of 35 MPa/700°C/720°C, and double reheat.

Bernero (2002) analyzed the operation of an ultra-supercritical power plant featuring a net capacity of 508 MW and steam conditions of 365 bar/700°C/700°C at a condenser pressure of 0.083 bar. An efficiency of 45% (LHV) is calculated, compared to 41.9% (LHV) for a supercritical plant with steam parameters of 290 bar/580°C/582°C and 38.3% (LHV) for a conventional non-critical pulverized combustion plant with steam parameters of 165 bar/538°C/538°C. The 20-years levelized cost of electricity are calculated as 7.54 $cents/kWh, 7.51 $cents/kWh, and 6.81 $cents/kWh, respectively.

However the costs for retrofitting an existing subcritical boiler to a supercritical steam system are prohibitive (IEA Clean Coal 2005a). Therefore, other ways to increase efficiency by retrofitting should be pursued or new ultra-supercritical plant should substitute old subcritical pulverized combustion units in order to improve the cost and environmental performance (including reduction of CO_2 emission rate) of average coal plants (IEA Clean Coal 2005a.

The lignite-fuelled power stations with optimized plant technology (known as BoA system in Germany) currently featuring an efficiency of 43% will be further improbed by lignite pre-drying (Euracoal 2005). In a fluidized bed the raw lignite is dried by low-pressure steam at low energy level without making direct use of fuel heat. This fluidized-bed drying technology (WTA) is expected to boost the overall efficiency of the BoA-Plus unit up to 47% efficiency (Euracoal 2005). This is referred to as BoA-Plus technology and is pictured in Figure 4.

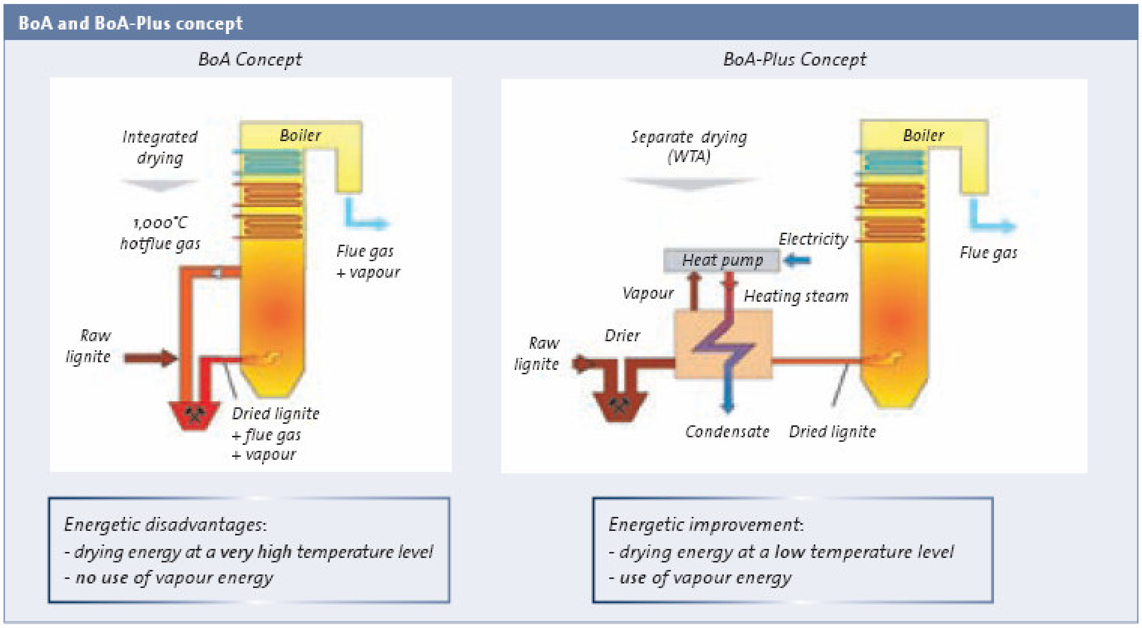

Figure 4 **BoA-Plus concept with lignite pre-drying (source: RWE).**

Another parameter and decisive requirement for high efficiencies of supercritical steam power plants is a low condenser pressure. Every 10 mbar increase in the condenser vacuum would result in approximately 0.39 percentage points to the plant exergetic efficiency under the conditions provided in the case study for the super-critical plant with 290 bar/580°C/582°C in (Bernero 2002). In addition, a low flue gas temperature is important for better system efficiencies. Also reduction of boiler auxiliary power consumption is worth of further consideration, as 6.0-7.3% of gross power output of a supercritical steam power plant is self-consumed (Bernero 2002).

Efficiencies of side aggregates can also play an important role in the overall power plant efficiency (EC 2005). Improvements in turbine blading shape can for instance result in a turbine efficiency improvement of 0.4 – 2%. The boiler design could be improved by using a horizontal furnace with horizontally rifled vertical furnace pipes, which would also reduce the construction costs (EC 2005).

Further improvement is also expected in the field of emission reduction. NOx-emission will be further reduced by integrated (combustion modification) and add-on (flue gas treatment) technologies. Low-NOx burners and furnace air staging is already technical proven, furnace fuel staging is in demonstration phase at present. As flue gas treatment technology Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction are commercially available (EC 2005). SO2 emissions will be further reduced by integrated technologies (reducing the sulphur content by coal preparation, coal gas desulphurization) and add-on (flue gas desulphurization, FGD) technologies.

1.3.3 Integrated Gasification Combined Cycle (IGCC) power plants

This subchapter discusses your third technology type in detail, if a third technology is needed. Otherwise it should be removed. Add more subchapters 1.3.x if necessary.

1.3.3.3.1 General

Integrated Gasification Combined Cycle (IGCC) is an emerging advanced power generation system having the potential of generating electricity from fossil fuels such as coal with high efficiency and with low emissions. In relation to coal combustion the IGCC technology produces less amounts of solid waste (ash and slag) and lower emissions of SOx, NOx and CO_2 referred to the kWh electricity produced (Australian Coal Association 2004, WCI 2005a). IGCC is one of the most efficient and cleanest technologies for coal-based power generation, with emissions to air comparable to those of natural gas-based power production in a gas and steam plant (DOE 2001).

1.3.3.3.2 Technology description and characteristics

An IGCC power plant consists of a gasification unit and a gas-fired combined-cycle unit. In the gasification unit a fuel gas is produced from coal, largely consisting of carbon monoxide and hydrogen. This high temperature coal gas is cleaned of impurities and subsequently fired in a gas turbine. A power generator coupled to the gas turbine produces electricity. The high temperature exhaust of the gas turbine still has enough heat to produce super-heated steam in a steam generator belonging to a conventional steam cycle. The super heated steam is drives a conventional steam turbine and produces electricity in the connected generator. (DOE 2004b, CCSD 2002, IEA Clean Coal 2005b)

That way a coal gasification power plant typically gets dual duty from the gases it produces – first in a gas turbine and secondly in a steam turbine. This use of two thermodynamic cycles in cascade, which gives the name of "combined cycle" to the technology, explains why gasification-based power systems can achieve high power generation efficiencies. (DOE 2004b). In comparison to a natural gas steam turbine the IGCC turbine has to cope with a much lower heating value of the syngas, thus requiring different design.

The process flow of an IGCC power plant is pictured in Figure 5.

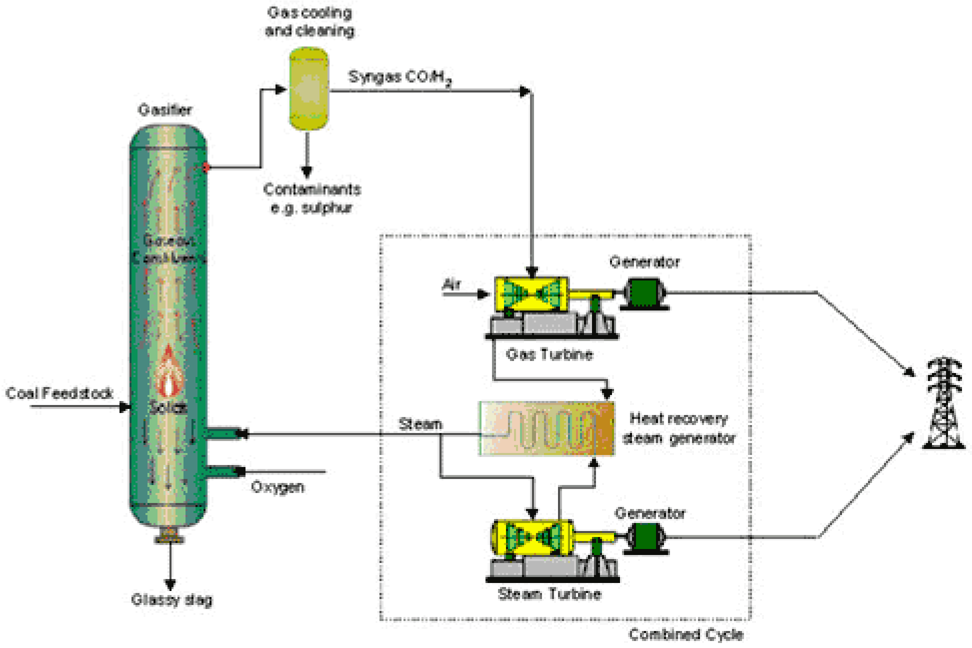

Figure 5 **Simplified process flow of an IGCC power plant (CCSD 2002)**

Currently, commercial gasification-based systems achieve high efficiency levels, typically in the mid 40s (WCI 2005b). Efficiencies close to 45% are cited (DOE 2004b, Australian Coal Association 2004).

An increase of the efficiency means that less fuel is used to generate the rated power, resulting in better economics (which can mean lower costs to ratepayers) and the formation of lower amounts of greenhouse gases per energy unit.

Starting from 45% IGCC technology can offer substantial increases in efficiency in the hot gas clean-up. Currently the gas cleaning stages for particulates and sulphur removal can only operate at relatively low temperatures, which limits the overall efficiency obtainable (IEA Clean Coal 2005b). Further efficiency improvements are expected through advances in gas turbine technology (higher pressure ratios, higher turbine entry temperatures, reheat).

With recent advances in gas turbine technology and current state of the art, IGCC designs offering efficiencies close to 50% are already available (WCI 2005b, Australian Coal Association 2004).

Within the Carnot Program of the European Union an efficiency of 51-53% is expected for IGCC in 2015 (EC 2001).

The further development and support of IGCC offers the prospect of net efficiencies of 56%in the future (WCI 2005b). In the same direction goes DOE citing that in future IGCC technology may be able to achieve efficiencies approaching 60% (DOE 2004b).

More optimistic are the forecasts from the German COORETEC project: Starting from a current efficiency of 45 - 48%, an efficiency of 54 – 57% is forecasted from 2010 to 2020. Past 2025 an IGCC efficiency of 62% is expected (BMWA 2003).

1.3.3.3.3 Feedstock and products

In addition to its high efficiency potential and excellent environmental performance, an IGCC power plant features high flexibility concerning feedstocks. Besides hard coal, IGCC power plants are fuelled by lignite, biomass, municipal and other solid wastes or residues of the petrochemical industry (DOE 2004b).

Besides electricity production there are alternative products that can be generated via coal gasification. Meanwhile coal gasification is an established route for producing hydrogen and there is considerable potential for hydrogen-producing IGCC plants (PowerClean 2004).

The syngas from coal gasification can also be used to produce chemicals and liquid fuels as well as for upgrading of refinery and petrochemical feedstock. These products have the potential to offset the cost of electricity generation using IGCC (Australian Coal Association 2004). This capability of co-production makes coal gasification one of the most promising technologies for the energy plants of tomorrow (DOE 2001).

Furthermore it is possible to produce ultra-clean fuels from syngas via Fischer-Tropsch synthesis (DOE 2001). These fuels contain no sulphur or nitrogen and are virtually free of aromatics. Fischer-Tropsch derived diesel fuel is of excellent quality, having a cetane number greater than 70, and can be used as a blending stock for low-sulphur gasoline production.

Besides fuel, the syngas can be used to produce methanol or higher alcohols. From methanol again several chemicals, such as formaldehyde, acetic acid, and other derivatives can be processed.

Co-production is of particular relevance for LCA. Since there are several end-products it is necessary to allocate the resources needed and the emissions released to each of the respective co-products. [To be addressed in next deliverable.]

1.3.3.3.4 Coal gasification

The heart of the gasification unit is the gasifier. It converts the hydrocarbon feedstock into gaseous components by applying heat under pressure in the presence of oxygen or steam. A gasifier differs from a combustor in that the amount of air or oxygen available inside the gasifier is carefully controlled to facilitate partial oxidation. Only a relatively small portion of the fuel burns completely, the main reaction is the generation of incomplete burned hydrocarbons from feedstock as gaseous constituents. The produced synthesis gas or “syngas” is primarily made of hydrogen and carbon monoxide (DOE 2004b).

The typical gasification (partial oxidation) reactions of a generic hydrocarbon can be exemplified by:

$$\boxed{C_xH_y + \frac{x}{2}O_2 \quad \rightarrow \quad xCO + \frac{y}{2}H_2}$$

Minerals in the fuel (i.e., the rocks, dirt and other impurities which don't gasify like carbon-based constituents) separate and for the most part leave the bottom of the gasifier either as an inert glass-like slag or other marketable solid products. Only a small fraction of the mineral matter is blown out of the gasifier as fly ash and requires removal downstream. The high temperature syngas leaving the gasifier is cleaned of impurities and subsequently fired in a gas turbine (DOE 2004b).

Sulfur impurities in the feedstock form hydrogen sulfide, from which sulfur can be easily extracted, typically as elemental sulfur or sulfuric acid, both marketable byproducts notwithstanding low market prices. Over 99% of the sulphur present in the coal can be recovered for sale as chemically pure sulphur (Australian Coal Association 2004). Nitrogen oxides, another potential pollutant, are not formed in the (reducing) environment of the gasifier. Instead, ammonia is created by nitrogen-hydrogen reactions. The ammonia can be easily stripped out of the gas stream. As much as 95-99% of NO_x and SO_x emissions are removed (DOE 2004b, WCI 2005a; WCI 2005b).

A way to make coal gasification more economical in future is to develop lower-cost ways to produce the oxygen used in the gasification process. Since pure oxygen isn't diluted by the large quantities of nitrogen present in air, oxygen-blown coal gasifiers can be more efficient. A further aspect is that they produce a gas stream with a higher concentration of CO_2 that can be more easily captured and sequestered.

Making oxygen today, however, typically involves an air separation unit with a complex, energy-intensive super-cooling (cryogenic) process to extract oxygen from the air (DOE 2004b). A much lower cost alternative under development is to use new innovations in ceramic membranes to separate oxygen from the air at elevated temperatures. (DOE 2004b). Membranes may also become an important new technology for separating gases produced by coal gasifiers. Membranes are explored and developed that can selectively remove hydrogen from syngas. Figure 6 shows the Texaco Entrained Flow Gasifier (CCSD 2002).

"The commercial gasification processes believed most suited for near-term IGCC applications using coal or petroleum feedstocks are the ChevronTexaco, Conoco Phillips, and Shell entrained-flow gasifiers. Each of these technologies is currently used at a commercial IGCC facility." (Financing IGCC 2004)

IGCC plants are characterized by the type of gasifier and the oxidant fed to the gasifier (oxygen or air) (Bernero 2002): There are moving-bed reactors, fluidized-bed reactors and entrained-flow reactors. Most IGCC plants in operation or under construction use entrained flow gasifiers, which are oxygen blown (Financing IGCC 2004). Only one IGCC plant is currently based on a fluidized bed gasifier, which is air-blown (IEA Clean Coal 2005b).

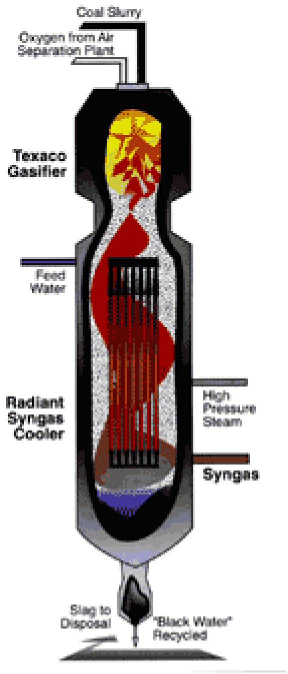

Figure 6 **Texaco Entrained Flow Gasifier (CCSD 2002).**

1.3.3.3.5 Flue gas cleaning/emissions and residues

The syngas produced in the gasifier must be cleaned of the particulate matter before feeding it into the gas turbine. There are two pathways for syngas cleaning, either wet scrubbing (cold conditions), which is presently applied, or gas cleaning in hot conditions. The wet scrubbing process is commercially practised in the industry but when applied to IGCC it lowers the efficiency of the plant by some 2% to 3%. This is due to loss of sensible heat in the gas during scrubbing. This can be prevented by cleaning the gas in hot condition. Hot gas cleanup is ultimately desired for IGCC, but presently this technology is still under development and is not commercial applicable.

1.3.3.2 Present market and use of IGCC technology

Despite the worldwide commercial use and acceptance of gasification processes and natural gas combined cycle power systems, until recently IGCC was cited still not to be established as a mature technology for electricity generation (Financing IGCC 2004). It was called ‘at demonstration stage on coal’ (EC 2001) or a ‘near commercial technology‘ (Australian Coal Association 2004).

Each major component of IGCC had been broadly utilized in industrial and power generation applications, but the integration of a gasification unit with a combined cycle power block to produce commercial electricity as a primary output was relatively new and had been firstly demonstrated at only a handful of facilities around the world

(Financing IGCC 2004). These milestone facilities of IGCC technology are shown in Table 2.

The IGCC plant in Cool Water in 1984 showed the technical feasibility of IGCC. The commercial feasibility was demonstrated at Polk Tampa Electric in 1996. Two variants of the entrained bed concept have been demonstrated at the commercial prototype scale at Buggenum (Netherlands) and at Puertollano (Spain). Both plants operate reasonably reliable with efficiencies of over 42% (LHV) and the Puertollano unit is widely regarded as the state of the art operational technology (Power Clean 2004).

All plants in Table 2 are mainly around 250 MW_e size, which mainly has its reason in the specification of the gasifiers. As gasifiers are pressure vessels, they cannot be manufactured on site but need to be transported. Hence, due to their weight and sheer size, capacities much above 300 MW_e are not likely (IEA Clean Coal 2005b).

However, meanwhile IGCC technology has further developed and more commercial IGCC power plants are operationalve at present. According to the recent status report on IGCC power plants by the World Coal Institute, there has been a strong increase of IGCC power plants. Currently there are around 160 IGCC plants worldwide (WCI 2005a). Around 16,500 MWe of IGCC capacity is expected to be operating in the USA by 2020 (WCI 2005a, NMA 2005)

Table 2: Some commercially operating IGCC plants; after (Financing IGCC 2004).

	Cool Water Demonstration Plant	**Wabash Power Station**	**Polk Power Station**	**Willem Alexander**	**Puertollano**
Location	California, US	Indiana, US	Florida, US	Netherlands	Spain
Capacity (MW net)	120	262	250	253	298
Gasifier	Texaco	Conoco Phillips	Chevron Texaco	Shell	Prenflo
Gas Turbine	GE 7E	GE MS 700IFA	GE MS 700IFA	Siemens V 94.2	Siemens V 94.2
Efficiency (% HHV)	33	39,7	37,5	41,4	41,5
Heat rate (Btu/kWh HHV)	Unk.	8,600	9,100	8,240	8,230
Fuel Feedstock	Bit. coal	Bit. Coal / pet coke	Bit. Coal/ pet coke	Bit. coal	Bit. Coal / pet coke
Year of commissioning	1984	1995	1996	1994	1998

All the current coal-fuelled demonstration plants are subsidised. The European plants are part of the Thermie programme, and in the US, the DOE is partly funding the design and construction, as well as the operating costs for the first few years. Some plants are repowering projects, but from the point of view of demonstrating the viability of various systems, they are effectively new plants, even though tied to an existing steam turbine. (IEA Clean Coal 2005b)

1.3.1.3 Future technological improvements and developments of IGCC technology

On the way to the next generation of IGCC power plant technology there are several areas that are anticipated to be further researched and developed. Based on experiences and operational problems obtained with current IGCC technology several points of projected research development in the short- and long-term future can be listed:

- Availability problems with the existing large units still have to be fully resolved.
- Development of materials to ensure greater reliability, especially refractories, improved dry feeding, particularly for mixed feedstocks, improved fire-tube cooler designs with regard to minimising deposition and corrosion (PowerClean 2004).
- Development of corrosion resistant, high temperature materials and coatings with mitigated material fatigue (APGTF 2004, BMWA 2003).
- Further integration of the various components to ensure a lower capital cost for the system (PowerClean 2004).
- Further improvement of combustion control in terms of flame stability and pollutant production at co-firing (APGTF 2004).
- Hot gas clean up: pollutant removal (dust removal, desulphurisation) from higher temperature gas streams (APGTF 2004).
- The anticipated increase of efficiency is directly coupled with the development of gas turbine technology (PowerClean 2004). An important step is the development of improved syngas turbines with materials applicable by 650°C (BMWA 2003).
- Further development of high temperature fuel cells: Future concepts that incorporate a fuel cell or fuel cell-gas turbine hybrid could achieve even higher efficiencies, perhaps in the 60 percent range (Australian Coal Association 2004).
- Membrane technology may also become important for separating gases produced by coal gasifiers or for the provision of oxygen for the gasification process. Considerable energy saving and cost reduction is expected from membranes for O_2 separation (APGTF 2004). New inorganic membrane based systems may reduce the energy requirement for cryogenic separation from 235 kWh/ton O_2 to less than 150 kWh/ ton O_2 (EC 2005).

1.3.4 Future [your power source] Technologies.

This subchapter discusses the future technologies in detail. Similar content as above, except the future dimension is included. The development of key parameters has to be included. 1-3 pages.

The following chapter could also be excluded

1.3.4.1 Potential socio-economic implications

Experience with the deployment of energy technologies has shown that public acceptance is crucial to their commercial success (APGTF 2004). When investigating future technologies for electricity generation it is important to also identify the technical and perception issues that influence the acceptance of general public.

A list of socio-economic factors (positive / negative prerequisites for acceptance by the population) for future coal-fired technologies follows.

+ Relatively long-term and widely distributed world-wide resources of coal
+ High market penetration of PC and acceptance in several conditions
+ High efficiency and a low or even very low (“zero”) emission level
+ IGCC: High flexibility in terms of feedstocks (hard coal, lignite, biomass, petrochemical residues) but with variation of cost/efficiency to be taken into account; possibility of co-firing with biomass
+ IGCC: possible co-production of hydrogen and sequestration of CO_2

- High costs and modest experience of IGCC
- Decrease of efficiency in consequence of CO_2 sequestration
- Additional costs for CO_2 sequestration
- Concerns for potential CO_2 releases during sequestration or transportation.
- Concerns for potential CO_2 leak or releases from storages within historical times

1.3.4.2 Hybrid gasification/combustion systems

Future concepts that incorporate a fuel cell or a fuel cell-gas turbine hybrid could achieve high efficiencies, nearly twice as much as today's typical coal combustion plants (DOE 2004b). Fuel cells convert the chemical energy of a fuel, such as hydrogen, directly into electricity at high rates of efficiency and with almost no emissions. Emerging fuel cells have efficiency levels of 60% (WCI 2005b). Some fuel cells types also produce very high-temperature exhaust gases that can either be used directly in combined-cycle or used to drive a gas turbine. If any of the remaining waste heat can be channeled into process steam or heat, perhaps for nearby factories or district heating plants, the overall fuel use efficiency of future gasification plants could reach 70 to 80 percent (DOE 2004b).

1.3.4.3 Hybrid IGCC with fuel cells

The efficiency of power generation from syngas (produced from coal) could be improved by the use of a fuel cell in the power cycle. Such a hybrid system promising high efficiency is called Integrated Gasification Fuel Cell (IGFC). The total potential efficiency of a gasifier – fuel cell – gas/expansion turbine – steam turbine cycle could be as high as 65 per cent with a consequent substantial reduction in greenhouse gas emissions intensity of the order of 40-50 per cent compared to Ultra supercritical technology (Australian Coal Association 2004). This also substantially reduces the load upon and cost of carbon capture and sequestration. IGFC hybrids have the potential to achieve near-zero emissions, because the concentrated CO_2 produced can be removed by separation. Thus high efficiency while capturing CO_2 is possible with IGFC (WCI 2005a; WCI 2005b).

1.3.4.2.1 High temperature / high pressure fuel cells for IGFC

For a coal gasification power station involving fuel cells, MW-scale fuel cells must be developed (Australian Coal Association 2004). At present only Molten Carbonate Fuel Cells (MCFC) are available at a modest MW-scale and it is understood that these would benefit from further significant development. Another promising type of fuel cell for MW-scale application is the Solid Oxide Fuel Cell (SOFC) (Australian Coal Association 2004). Within the Clean 21 program of the Australian Coal Association it was started to develop KW-scale fuel cells together with a leading fuel cell company. In the action plan of Clean 21 it is assumed that in the longer term, fuel cells could contribute substantially to facilitating large scale power generation from hydrogen derived from coal (Australian Coal Association 2004).

The use of fuel cells has been demonstrated at the 2 MWe size and they can be used modularly. (WCI 2005a; 2005b)

Currently fuel cells require further development for application in large stationary power plants and are not currently competitive with gas- and steam turbine-based combined cycles for power generation or in transportation applications. (WCI 2005b)

The New Energy and Industrial Technology Development Organization (NEDO) is undertaking a major project to develop coal gasification for use in fuel cells. The project is known as EAGLE (coal Energy Application for Gas, Liquid and Electricity) which started in 1998 and is due to run until 2006 (WCI 2005b). A pilot plant has been constructed, which aims to develop a coal gasifier suitable for IGFC. The integrated coal gasification fuel cell combined cycle system should achieve efficiencies of at least 53-55%. Deployment of IGCC-fuel cells in Japan is expected to begin in 2010, with the introduction of 50MWe distributed power generation installations, followed by the introduction of a 600MWe system for utility use by 2020 (IEA Clean Coal 2003).

The US Department of Energy (DOE) has formed the Solid State Energy Conversion Alliance (SECA)[3] with a goal of producing a core solid-state fuel cell module that would be able to compete with gas turbine and diesel generators and likely gain widespread market acceptance.

The SECA Program is currently focused on small, 3-10 kW scale fuel cell systems for distributed generation applications. These relatively small fuel cells can be scaled up to larger megawatt class systems for use as power modules in coal based applications,

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[3] http://www.fe.doe.gov/programs/powersystems/fuelcells/fuelcells_seca.html

including FutureGen. Large fuel cell systems will then be combined with other power generation modules (e.g., a gas turbine as a fuel cell-turbine hybrid), into hybrid power systems. The ultimate goal of this new initiative is the development of large (> 100 MWe) fuel cell power systems that will produce affordable, efficient and environmentally-friendly electrical power at greater than fifty percent (50% HHV) overall efficiency from coal to AC power, in systems that include CO_2 separation for sequestration. (DOE 2004b)

1.4 Present [Your technology] Market

This chapter is for presenting the position this technology has on the present energy generation market and what is the share between the different types of devises (if many). 1-2 pages.

1.5 Future development

This chapter describes the future of the market and technical issues. Key figures have to be included for years 2010, 2020 and 2030. They should include at least costs (investment, fuel, operation and maintenance), efficiency, CO_2 emissions, etc. (to be defined later). 1-2 pages.

It is expected that in the next decades the overall condition is such that research and development for fossil technologies will progress steadily and deployment of improved and advanced fossil technologies will continue in the EU as well as worldwide.

Since IGCC power plants still are in their early stage of development, supercritical steam power plants will probably be the preferred coal-based power generation technology for installation of new capacity in the short-term, with a development towards more advanced steam conditions. Due to their relative flexibility concerning fuel type and their good environmental performance, IGCC power plants can also efficiently use fuel feedstock such as biomass and refinery residual. Moreover, IGCC systems could be part of a particularly clean power plant system, integrated with advanced gas turbines and fuel cells.

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