EUROPEAN PARLIAMENT

DG II / INTERNAL POLICY

CLEAN COAL TECHNOLOGY

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Executive Summary

This paper tries to address briefly the actual and future role of coal - in the EU and in a global context. But if coal will continue in the future to play a major role coal must be able to meet the challenges of environmental sustainability. Thus, coal (like other carbon - intensive energy sources) must significantly reduce its potential greenhouse impacts if it is to claim a continuing and sustainable role in the global energy mix. After some general remarks concerning coal, the following paper tries at first to describe briefly the environmental challenges coal is facing today.
The main objective of the following paper is to give an overview concerning clean coal technologies (CCT) - i.e. both the current available technology potential and also the next generation (future) technologies.

Challenges, opportunities and demand for high efficiency power plants

For the following, see a recent study commissioned by the European Parliament (EP) on Clean Coal Technology (EP 2003)

In the EU today, energy supply is very much dependent on oil and gas, energy resources which have to be imported mostly from non-EU countries. The EU therefore faces the danger of steering towards a situation where its economic growth relies on a fuel/energy supply from a small number of non-member countries and is thus further away from self-sufficiency. At current levels, secured coal reserves are estimated to last for more than 200 years. This means that coal users can secure their energy supply in the long run, and can do so at competitive prices.

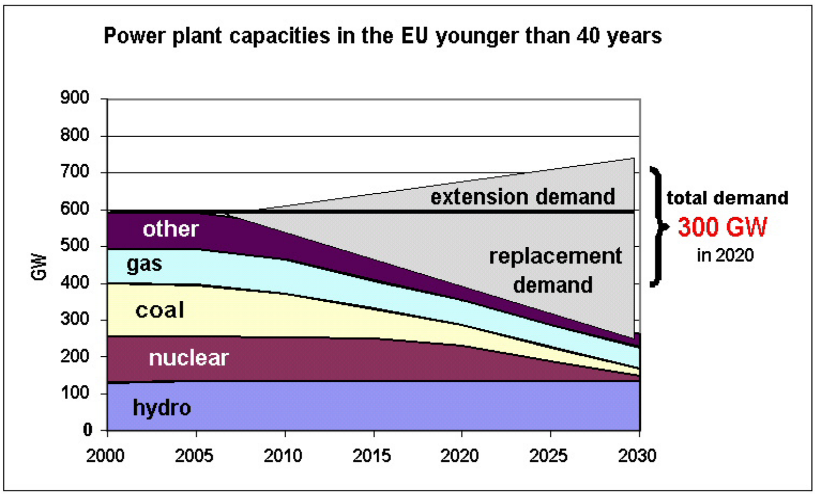
The real structural change of the European energy sector is based on the liberalisation of the electricity (and other energy carrier) markets, and secondly on the support of renewable energy technologies. Electricity production facilities not only have to meet the faster changing power demand but must also, to a certain extent, promote short-term solutions with stricter cost-benefit calculations than long-term investments with less calculable risks even though they might be environmentally more benign. Contrary to CCT on a large scale, smaller gas-fired units with short planning and construction periods and lower capital commitment are flexible to meet this criterion, despite the higher and less calculable fuel costs, the higher dependencies from a few exporting gas producers and the more limited gas reserves. Additionally, gas is an ideal fuel for households and decentralised smaller users, as complex flue gas cleaning (only economic on a large-scale) is hardly needed.

In contrast, coal offers the advantage of secured supply and prices, but requires a more complex flue gas cleaning process which is only economical for large-scale plants. In order to be able to explore the benefits of high efficient and clean coal technologies for power generation, which is best possible in larger units, political support is requested to provide the necessary medium- to long term planning security. It is the dilemma that on the one hand political influence in the power sector is contradictory to the basic idea of the liberalisation and on the other hand there is a need for fast development in the next generation of CCT, which meets the demands for efficiency and flexibility in current and future market conditions.

The US government has started to invest vast sums to increase the efficiency of US power plants through technological improvements over the next years. Consequently, while they have withdrawn from their Kyoto protocol responsibilities, they might override the European industry in building plants with the highest efficiency. The EU will need to fulfil exactly these responsibilities. Thus, even if we turn away from oil and gas and towards coal for electricity production, we might still find the EU dependent on other countries – this time from a technological view point – if the EU don't invest into the future of the European power plant industry.

The European Commission has not only acknowledged the need to withdraw from a reliance on fuels not widely available within the EU, but also the necessity for further development of available technologies: "Coal's future depends largely on the development of techniques which make it easier to use … and lessen its environmental impact in terms of pollutant emissions through clean combustion technologies." (Source: EC 2000, COM(2000)769: Green Paper : Towards a European Strategy for the Security of Energy Supply). Looking at all aspects raised in the Green Paper and documents from EC DG TREN and those mentioned in the introduction of the 6th Framework programme on RTD, increased energy production, on the basis of advanced clean fossil technologies, is mandatory for overcoming the challenges for a sustainable development.

It is all the more surprising that Clean Coal Technology plays a very minor part in the 6th Framework Programme for RTD. Investments into Clean Coal Technology Research, for example the ultra-supercritical 700°C power plant, are essential to the future of the EU regarding the security of sustainable energy supply, climate control, and economic growth.



A secure energy supply requires sustained power plant equipment in all fields of thermal energy production. In order to meet the increased global demand and avoid power shortages like those in the US, new investments in fossil PP in Europe are mandatory in the forthcoming two decades for an additional capacity of about 300 GW, delivering annually some 10.000 TWh;

Key Observations and Conclusions concerning the actual and future role of coal

- Coal generates 38,7% of global electricity.
- Many countries, including EU member and accession states, are heavily dependant on coal for electricity production.
- Coal reserves are much larger than those of oil and gas, with a confirmed global reserves-to-production ratio of over 230 years.
- By 2030, global coal use is expected to have doubled from today's levels (IEA).
- By 2030, coal is expecting to generate 45% of global electricity (WETO).
- Advanced power generation from coal is expected to become cheaper than from gas by 2025 without action to reduce costs, and by 2015 with R&D (WETO).
- Coal generates 38,7% of global electricity.
- By 2030, Europe must build 550 GWof new capacity, at a cost of €400 billion.
- This new plant will operate through the period of declining oil and gas supplies.
- It will not be possible to base such large capacity on renewable energy sources.
- Therefore, a very large proportion of this new plant will have to be based on new, advanced, clean coal technology.
- Coal has a very strong strategic role to play in the context of security of supply because of the amount available, its wide distribution, ease and low cost of transport, and its history of price stability. Its use would reduce EU dependence on a single source and a single fuel.
- The global power plant market to 2030 is about €3600 billion, of which coal-fired plant will represent €1450 billion.
- Historically, Europe has built half of the world's power stations, so Europe could hope to capture 50% of this market plus about €175 billion in spares, maintenance and repairs.
- This must be won in the face of competition from USA, Japan and companies within the target markets.
- The USA and Japan have significant long-term strategic programmes to develop clean coal technologies to meet future domestic and export market requirements.
- Affirmative R&D action is needed to support the EU power industry, working together on a Europe-wide basis, to establish the clean use of coal and other fossil fuels in near-zero emissions power plant. The role model would be the European Research Area, as in the FP6 programme, but with more a comprehensive range of technical objectives recognising the importance of fossil fuels for achieving an overall future.

Source: PowerClean 2003

1. Introduction

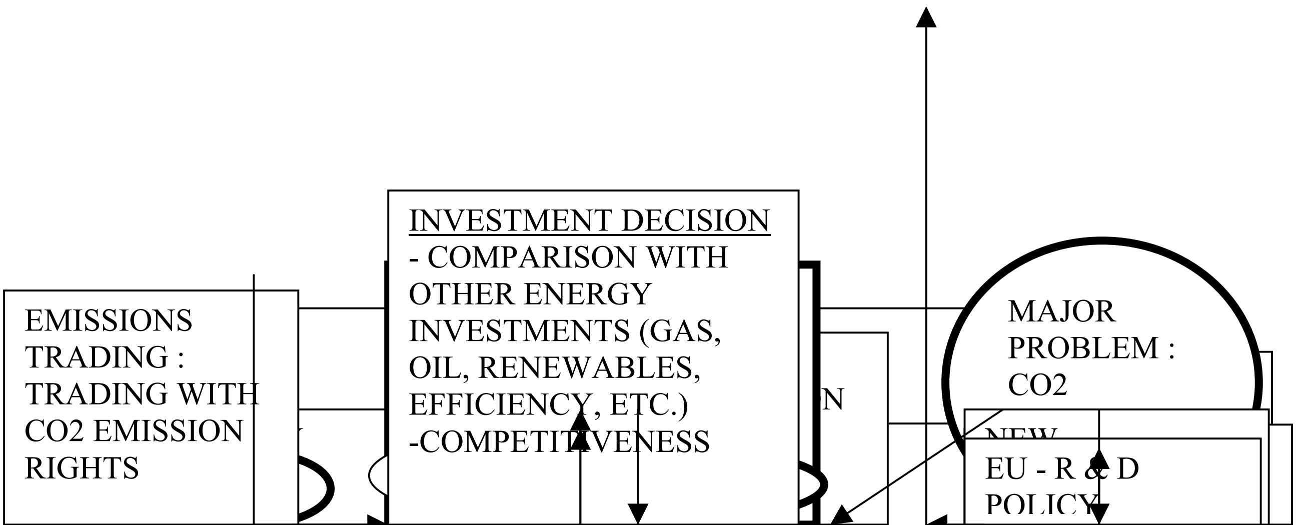
This paper gives a short overview on coal policy in general - and particularly concerns future energy demand and the need for a balanced energy mix. It is assumed that coal will be able to meet essential environmental requirements - if not, coal will be abandoned.
Clean coal technologies will play the key role in meeting the necessary environmental requirements.
The paper does not discuss the pros and cons of the future role of fossil fuels in an environmentally friendly energy strategy, but briefly describes clean coal technologies which can bring the use of coal into line with the essential environmental requirements.
Discussion of the essentials for an environmentally friendly coal policy and the survey of clean coal technologies is based on existing literature (see:Bibliography / References / Links).

2. Coal and its role in the EU energy strategy

Coal today plays an important role in EU energy strategy. If coal is to keep this important role in the mid-and long term perspective (with its high contribution to the EU energy supply) its use has to be in line with overall EU energy objectives.
As Figure 1 indicates, coal contributes fully to the goal of "security of supply" and is more or less in line with the overall "economic goals" (i.e. : market integration, deregulation, pricing policy and competitiveness). However,there is a major problem with the objective "protection of the environment" (especially: CO_2 -reduction).
This incompability can be solved or reduced by:

- CO_2 - Sequestration
- Clean Coal technology (CCT).

EU R&D policy could play an important role for the development and deployment of new technologies, especially CCTs.
The investment decisions concerning coal depend (Figure 1) on a comparison with other energy investments and their respective competitiveness. Investment decisions could in future be highly influenced by Emissions Trading (starting already in the EU in 2005) and the respective price of CO_2 - Emission Rights.



3. Coal: Facts and Statistics

In the 25-member EU, coal is king as far as energy production is concerned (22,4% in 2002; but only 12,9% in EU 15) - thus revealing that the enlarged EU is more "carbonized" (see Table 3). As far as direct use for final consumption is concerned, coal plays a minor rule (only 9,8% in EU15 in 1980, shrinking to 2,6% in EU 15 in 2002 (see : Table 5, EP 2004).
On a global scale (see WCJ 2004a):

- Coal provides over 23% of global primary energy needs and generates over 38% of the world's electricity

- Total global hard coal production increased rapidly: over 46% growth over the past 25 years. Strong growth in China and India accounted for most of the increase in hard coal production in 2002.

- Reserves: Coal resources are available worldwide, with recoverable reserves in around 70 countries. At current production levels, proven coal reserves are estimated to last over 200 years. In contrast, proven oil and gas reserves are equivalent to around 40 and 60 years respectively at current production levels. Over 70% of oil and gas reserves are in the Middle East and the Former Soviet Union.

- Major Producers of hard Coal in 2002: PR China with 1326Mt, followed by USA (917 Mt) and India (334 Mt)

- Coal in electricity generation:

Coal is the major fuel used for generating electricity worldwide - countries heavily dependent on coal for electricity include in 2002:

Poland	94,8%
China	76,2%(2001)
USA	49,9%
India	78,3%(2001)
Germany	52,0%
EU15	27,2%

4. Growing Energy Demand : the need for a balanced energy mix

Positive and negative points of energy sources

The energy sector faces major challenges in the 21st century. It will have to continue to supply secure and affordable energy in the face of growing demand (for the following see: WCI 2004a). Even with energy conservation measures in developed countries, global energy consumption will continue to increase, driven by economic growth and the needs of developing countries. Overall demand is projected to increase by almost 70% over the next 30 years, with most of that growth coming from developing countries [IEA 2002a]. Even then 1,4 billion people in developing countries will still not have access to electricity in 2030 [IEA 2002a].

At the same time, society is demanding cleaner energy and less pollution. The desire for lower emissions has led to widespread questioning of the role of fossil fuels in general and of coal in particular.

The industry has accepted and is responding to the call for improved environmental performance from the use of coal.

Most of the growing demand for energy will take place in developing countries. A third of it will be in China and India alone. At present, the average citizen of these countries uses just one-seventh as much energy as the average OECD citizen [IEA 2002b]. Inevitably, development in these countries will narrow this gap, necessitating a significant increase in their reliance on electricity and transportation and requiring major new supplies of energy.

To meet this need, the world cannot ignore any of the sources of energy available - especially coal, being the most, abundant and affordable of all the fossil fuels. All fuels will have to play their part and coal's role will be a vital one.

All forms of energy production have their impacts - negative as well as positive. There is no truly risk, wether in terms of human physical safety, security of supply or environmental impact.

The most effective way of reducing these risks is for policies to encourage a portfolio of investments - a diverse energy mix, where the strengths of one for the disadvantages of others.

The role of renewable sources of energy will increase in a world committed to sustainable development. Other fuels will have to provide the great bulk of the - additional - energy required over the period. As the most important fuel for electricity generation, coal will have a major and vital role to play, along with other fossil fuels.

Fuel	**Positive points**	**Negative points**
Coal	- Abundant, affordable, safe, secure. - Easy to transport and store. - Widely available.	- The most carbon intensive fuel for electricity - Poses technological challenges as part of low global CO_2 growth.
Oil	- Convenient. - Easy to transport and store. - No effective substitute in transportation uses.	- Carbon intensive. - Price volatility. - Resource concentration. - Vulnerability to disruption or geopolitical instability. - Transport risks.
Gas	- Efficient and convenient. - Fuel of choice for many uses, such as residential heating.	- Carbon intensive. - Expensive and risky to transport and store. - Requires dedicated, inflexible infrastructure. - Price volatility. - Resource concentration.

Nuclear	- Carbon-free generation. - Few resource constraints.	- Public acceptability. - Waste disposal question marks. - Capital intensive - may be uneconomic in some markets.
Renewables	- Low emissions on a life cycle basis. - Sustainable	- Generally high cost. - Intermittent sources. - Major expansion will take time. - Potential siting problems.

Resource base

That coal can continue to supply the world's energy is not in doubt. The IEA has stated: "World reserves of coal are enormous and, compared with oil and natural gas, widely dispersed...The world's proven reserve base represents about 200 years of production at current rates. Proven coal reserves have increased by over 50% in the past 22 years. The correlation of strong growth of proven coal reserves with robust production growth suggests that additions to proven coal reserves will continue to occur in those regions with strong, competitive coal industries" [IEA 2001]. In other words, there is no resource constraint on the use of coal, as far into the future as we can reasonably look.

Vulnerability to short-term disruption

There is also a short term dimension to energy security - minimising the risk of supply disruptions, wether by accident, political intervention, terrorism or industrial dispute - which is ever more important in our modern world. Developed countries are increasingly dependent on electricity-based systems - it is difficult to imagine a world in which such systems ceased to function - while the needs of developing countries are even more direct and basic - access to energy is a route to a better life and its absence can mean, literally, darkness and discomfort.

Coal has an immensely valuable role in this respect, complementing other fuels and energy sources that are generally more vulnerable to disruption.

Coal contributes to security of the energy mix in a variety of ways:

• Coal reserves are very large and will be available for the foreseeable future without raising geopolitical or safety issues.

• Coal is readily available from a wide variety of sources in a well-supplied worldwide market.

• Coal can be easily stored at power stations and stocks can be drawn on in emergencies.

• Coal-based power is not dependent on the weather and can be used as a backup for wind and hydropower.

• Coal does not need high pressure pipelines or dedicated supply routes.

• Coal supply routes do not need to be protected at enormous expense.

These features help facilitate efficient and competitive energy markets and help stabilise energy prices through inter-fuel competition.

5. Coal and the environment

With its vast, low-cost resource base, there is no doubt that coal can continue to contribute to economic growth and social development (for the following see: WCI 2004b). But the industry recognises that it must also be able to meet the challenge of environmental sustainabillity. In particular, coal and other carbon-intensive energy sources must significantly reduce their potential greenhouse impacts if they are to claim a continuing and sustainable role in the global energy mix.

The coal industry is committed to this objective and believes it can be achieved, primarly through the development and deployment of clean coal technologies.

The environmental Challenge and Response

The key environmental challenges facing coal, and the nature and status of the technological responses to those challenges, are summarised in the table below.
As the table shows, coal's technical response to its environmental challenges is ongoing and multifaceted. However, it can be said to have three core elements:

1. Eliminating emissions of pollutants such as particulate matter and oxides of sulphur and nitrogen. This has largely been achieved and the issue now is the application of 'off-the-shelf' technology.
2. Increasing thermal efficiency to reduce CO_2 and other emissions per unit of electricity generated. Major gains have already been achieved and further potential can be realised.
3. Eliminating CO_2 emissions. The development of 'zero emissions technologies' has commenced and is accelerating rapidly.

   A fourth dimension is the potential for coal to provide an essential source of hydrogen for completely clean future energy systems for stationery and transport applications. This would see coal not just put its own house in order, but become a mainstay of an effective and lasting global response to climate change.

Environment Challenges	***Technological Responses***	***Status***
Particulate Emissions Such as ash from coal combustion. Particulates can affect people's respiratory systems, impact local visibility and cause dust problems.	Electrostatic precipitators and fabric filters control particulate emissions from coal-fired power stations. Both have removal efficiencies of over 99,5%.	Technology developed and widely applied both in developed and developing countries.
Trace Elements Trace element emissions from coal-fired power stations include mercury, selenium and arsenic. They can be harmful to the environment and to human health.	Particulate control devices, fluidised bed combustion, activated carbon injection and desulphurisation equipment can all significantly reduce trace element emissions.	See: NO_X

Environment Challenges	***Technological Responses***	***Status***
NOx Oxides of nitrogen, referred to collectively as NOx , are formed from the combustion process where air is used and/or where nitrogen is present in the fuel. They can contribute to smog, ground level ozone, acid rain and greenhouse gas emissions.	NOx emissions can be cut by the use of low NOx burners, advanced combustion technologies and techniques such as selective catalytic reduction and selective non-catalytic reduction, which lower emissions by treating the NOx in the flue gas. Over 90% of NOx emissions can be removed using existing technologies.	Technologies developed, commercialised and widely applied in developed countries.
SOx Oxides of sulphur(SOx), mainly sulphur dioxide (SO_2), are produced from the combustion of the sulphur contained in many coals. SOx emissions can lead to acid rain and acidic aerosols (extremely fine air-borne particles).	Technologies are available to minimise SOx emissions, such as flue gas desulphurisation and the advanced combustion technologies described in the Annex. Emissions can be reduced by over 90% and in some instances by over 95%.	The application of NOx control and desulphurisation techniques is less prevalent in developing countries and, although increasing, could be more widely deployed.
Waste from Coal Combustion Waste consists primarily of uncombustible mineral matter (with a small amount of unreacted carbon).	Waste can be minimised both prior to and during coal combustion. Coal cleaning prior to combustion is a very cost-effective method of providing high quality coal; it reduces power station waste and emissions of SOx, as well as increasing thermal efficiencies. Waste can also be minimised through the use of high efficiency coal combustion technologies - the residual waste can then be reprocessed into construction materials.	Technologies developed and continually improving. Awareness of opportunities for the re-use of power station waste (e.g. fly ash in cement making) is steadily increasing.
Carbon Dioxide (CO_2) Reduction Carbon dioxide is the main oxide of carbon produced when fuels containing carbon are burnt. Carbon dioxide is a significant greenhouse gas; progressively reducing CO_2 from fossil fuel based power is an essential element of a	In the short to medium term, substantial reductions in the greenhouse intensity of coal-fired generation (CO_2 per megawatt hour of electricity produced) can be achieved by increased combustion efficiency (megawatt hours per tonne of coal consumed).	The efficiency of pulverised coal generation increased substantially during the latter part of the 20th century and, with the development of supercritical and ultrasupercritical processes, will continue its steady upward advance over the next

global response to the risks of global warning and climate change.		two decades. Circulating fluidised bed combustion technology offers similar benefits to advanced pulverised coal combustion and is well suited to co-combustion of coal with biomass.
CO_2 Elimination The virtual elimination of CO_2 emissions from fossil fuel based power - including coal-fired generation - offers the prospect of reconciling growing energy demand with the long term global goal of stabilising the concentration of greenhouse gases in the atmosphere at an acceptable level.	'Zero-emissions technologies' (ZET) to enable the separation and capture of CO_2 from coal-based generation and its permanent storage in the geological subsurface.	CO_2 separation, capture and geological storage technologies have been developed beyond the stage of technical feasibility. Researchers and technicians are planning to improve these component technologies and demonstrate them in integrated configurations. Deployment may start within a decade.

Source: WCI 2004 b

Efficiency increase of coal-fired stream power plants

Today 38% of the electricity produced worlwide comes from coal-fired power plants. This share will presumably continue to rise until the year 2020, and coal output used for power generation will certainly increase. Therefore, the further development of coal-fired power plant technology to even higher efficiencies is a great challenge that will allow the ambitious CO_2 reduction targets for precautionary protection against the global greenhouse to be met.

In the short term, a rise in efficiency of coal-fired power plants beyond the state reached can only be achieved by a further development and optimization of the conventional PF-fired steam power plant. This calls for systematic improvements in the field of fluid mechanics, thermodynamics, materials and the pre-drying of lignite. Raising the process parameters will make efficiencies of ca. 50% possible even for coal-fired plants in the medium-term, i.e. by ca. 2020.

Various development projects have been launched on a national and European level in order to tap the improvement potentials mentioned. Of central importance to an efficiency increase in steam power plants is the development and testing of high-temperature and anti-corrosive materials. Such materials will be available within the next 10 years, and this puts a steam power plant with process parameters of 700° C and 375 bar within the range of feasibility. Over the next few years, endurance tests of the new materials and components are planned to be carried out in a component test plan that will be erected at the cost of some €16 million (COMTES 700).Concomitant material qualification is envisaged to be perfomed by means of practice tests in one lignite- and one hard coal-fired power plant.

(See: Engelhard / Ewers / Altmann)

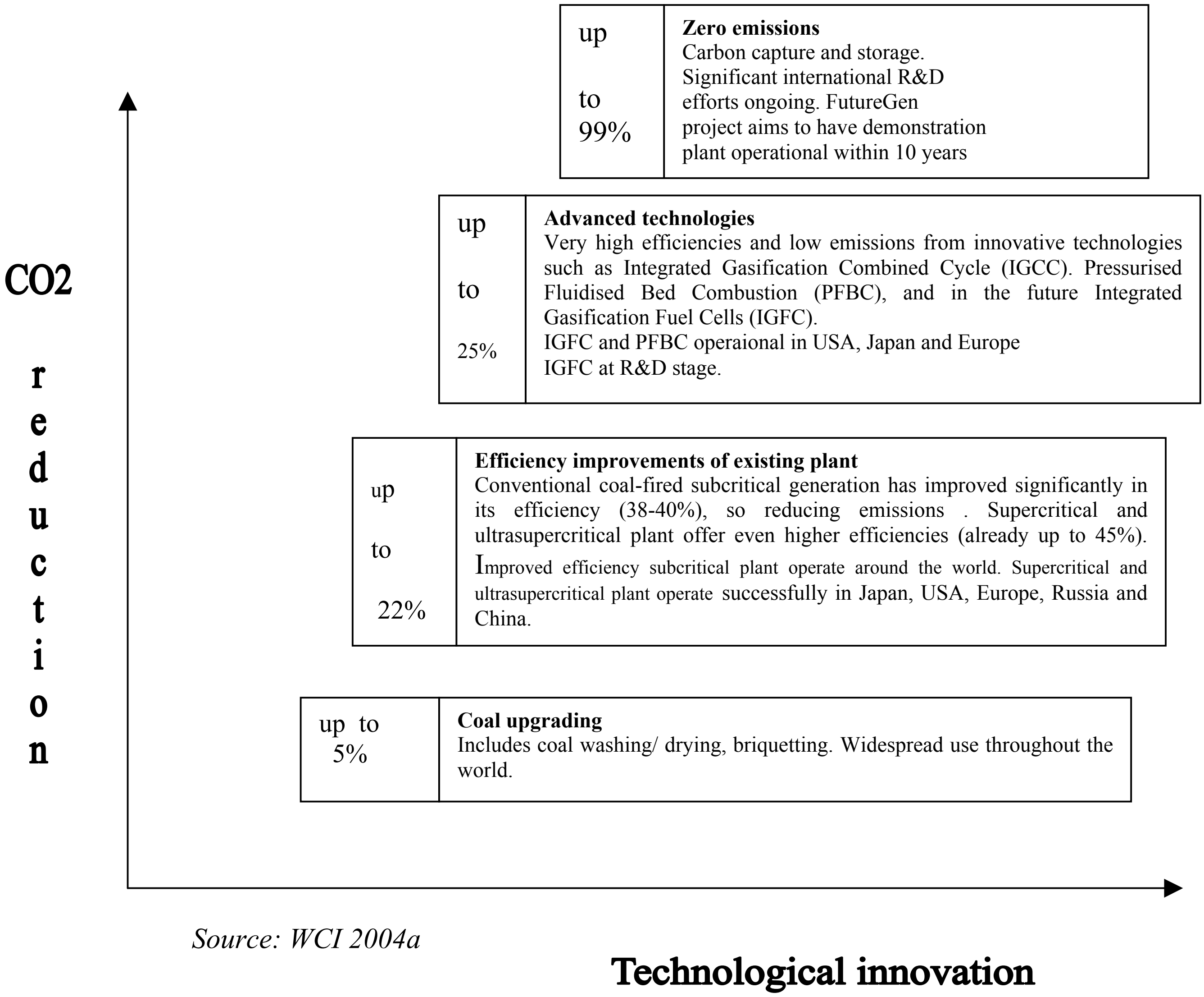
Different options are appropriate to different circumstances. In particular, the technologies that are viable in a developed country may not be as relevant to developing economies - typically, developing countries are unable to afford highly complex and expensive new technology and supporting infrastructure.

There is a road along which progress can be made towards better environmental performance, whatever the starting point (see the following diagram "The Coal-fired route to CO_2 reduction"). Already, in many developed countries, the main environmental challenges listed in the table above have effectively been met or are within reach - the technologies to deal with emissions of particulates, SOx and NOx not only exist, but have already been widely deployed in a number of countries. In other countries the focus may be on introducing the cleaner technologies already available, significantly reducing the environmental impacts of coal use.

This road continues forward into the future and offers an effective and realistic route to meeting the main challenge of the 21st century - reducing greenhouse gas emissions. The first step along this road is improvements in efficiency, which can reduce emissions of both pollutants and carbon dioxide per unit of power generated.

The efficiency of older plant in many developing countries is only around 30%, compared with the OECD average of around 36% - the transfer of new technology from developed to developing countries is vital to achieving efficiency improvements worldwide. New supercritical plant can achieve overall thermal efficiencies in the 43-45% range. In most countries, such plant is already fully commercial - in other words the efficiency gains and emissions reductions can be made without incurring significant social costs.

The Coal-fired Route to CO_2 Reduction



Source: WCI 2004a

A one percentage point increase in efficiency reduces emissions by around 2%. Upgrading or replacing older plant can therefore yield very singinficant CO_2 reductions - from 10% to 25% depending on the circumstances. Such reductions would be fully consistent with the overall trajectory of lower emissions needed to combat climate change.Since improved efficiencies also reduce other pollutants and overall fuel use, they can offer multiple benefits at relatively low cost.

Many developed countries are much further along the road of environmentally improved coal use, with the next challenge being to deploy advanced coal technologies, which offer the opportunity for efficiencies of up to 50% and higher. Further down the road is the vision of ultra low emissions power from coal, something that is already a focus of international research.

Coals plays a major role in all three pillars of sustainable development

Economic

- Coal produces 39% of the world's electricity (twice as much as the next largest source) and around 70% of the world's steel [IEA 2002a and WCI 2003a].
- Coal use in power generation is projected to grow 60% by 2030 [IEA 2002a].
- The benefits amount to a gain of billions of dollars to developed and developing countries alike.

Social

- 1,6 billion people in developing countries do not have access to electricity; for many, coal will be the route to electrification and a better lifer [IEA 2002a].
- Around 1 billion people have gained access to electricity via coal in the past two decades [WCI 2002a].
- Coal provides 7 million jobs worlwide and coal production is the key economic activity in many communities [WCI 2002a].

Environmental

- Emissions from coal burning have fallen substantially in recent decades even while consumption has increased.
- Development of modern advanced technologies can combine the economic and social advantages of coal with the need for environmental improvement.
- If coal-fired power stations across the world were brought up to current German levels of efficiency, the CO_2 reductions from this alone would be greater than from the Kyoto process [WCI 2003b].
- In the long term, new coal-based generation technology options, such as gasification and carbon capture and storage by geological sequestration, offer the possibility of ultra-low or zero emissions, at an acceptable cost.

Source: WCI 2004a

6. Clean Coal Technologies : a short survey

This chapter will only give a short and quick overview/ survey of actual and future clean coal technologies. An extensive overview on clean coal technologies is available in a recent EP-study (EP 2003).

6.1 Enhanced take up at existing options

Conventional coal-fired generation todays is normally via pulverised coal combustion (PCC) - coal is pulversised into a powder, which is burnt in a high temperature furnace to heat water and produce steam to drive a steam turbine (for the following see: WCI 2004 b). Modern PCC technology is well-developed, with thousands of units around the world, accounting for well over 90% of coal-fired capacity. Most of the coal-fired power plant worldwide that is not PCC is circulating fluised bed combustion (CFBC).
A range of options already exists to improve the environmental performance of conventional coal-fired power stations.
Coal cleaning by washing and beneficiation continues to play an important role in reducing emissions from coal-fired power stations. Coal cleaning can reduce the ash content of coal by over 50%, reduce SO_2 emissions and improve thermal efficiencies (leading to lower CO_2 emissions). While coal preparation is standard in many countries, it could be usefully extended in developing countires as a low cost-way to improve the environmental performance of coal use.

Particulate emissions can be reduced by methods such as electrostatic precipitators, fabric filters (also known as baghouses), wet particulate scrubbers and hot gas filtration systems. Electrostatic precipitators use an electrical field to create a charge on particles in the flue gas, so that the particles are attracted to collecting plates. Fabric filters collect particulates from the flue gas on a tightly woven fabric by sieving. Both electrostatic precipitators and fabric filters can remove over 99% of particulate emissions.

Global concerns over the effects of acid rain have led to the widespread development and utilisation of technologies to reduce, and in some cases eliminate, **emission of SO_2**. Flue gas desulphurisation (FGD) technology, for example, employs a sorbent, usually lime or limestone, to remove sulphur dioxide from the flue gas. FGD systems are currently installed in 27 countries and have led to enormous reductions in emissions - wet scrubbers, the most widely used FGD technology, can achieve removal efficiencies as high as 99%. The cost of FGD units has also reduced significantly, now costing one-third of what they did in the 1970s.

NOx reduction technologies include the use of low NOx burners, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). Low NOx burners and burner optimisation techniques are used to minimise the formation of NOx during combustion.

6.2 Deployment of Advanced Technologies

A range of advanced technologies has been developed, and continues to be enhanced, to make further reductions in the emissions of pollutants and to improve coal power plant efficiencies.

Fluidised bed combustion (FBC), in its various forms, can reduce SOx and NOx by 90% or more. In fluidised bed combustion systems, coal is burnt in a bed of heated particles suspended in flowing air. At sufficiently high air velocity, the bed acts as a fluid resulting in rapid mixing of the particles. This fluidising action allows complete coal combustion at relatively low temperatures. FBC systems are popular because of the technology's fuel flexibility; almost any combustible material can be burnt. In the USA, for example, FBC systems are increasingly utilised to burn abandoned piles of coal waste, turning what could otherwise be an environmental problem into a useful source of power.

The world's largest pressurised fluidised bed combustion (PFBC) plant is the 360MW Karita Power Station New Unit 1, located in Japan, and owned by Kyushy Electric Power. The PFBC combined cycle unit started commercial operation in July 2001 and replaced a heavy oil-fired unit, decommissioned in 1988.

The facility uses in-furnace desulphurisation to reduce emissions of SOx low temperature combustion and denitrification equipment to lower emissions of NOx and two-stage cyclones and an electrostatic precipitator to reduce dust emissions. The plant achieves net efficiency levels of around 41%.

The new PFBC combined cycle unit has led to significant environmental improvements compared to the old heavy oil-fired unit. The new facility has reduced NOx emissions by 70%, SOx emissions by 54% and particulates by 50%. Similarly, the 11% improvement in efficiency levels has resulted in a decline in CO_2 emissions.

Supercritical and Ultrasupercritical Power Plant Technology

Supercritical pulverised coal-fired power plant operate at higher steam temperatures and pressures than conventional subcritical PCC plant, and offer higher efficiencies - up to 45% - and hence lower emissions, including emissions of CO_2 for a given power output. Even higher efficiencies - up to 50% - can be expected in ultrasupercritical (USC) power plant, operating at very high temperatures and pressure.

In most countries supercritical plant are now commercial, with capital costs only higher than those of conventional plant and significantly lower unit fuel costs because of the increased efficiency and, in many cases, higher plant availability.

More than 400 supercritical plant are in operation worldwide, including a number in developing countries. The 2 x 600MW supercritical Shangai Shidongkou coal-fired power plant in China, for example, was put into operation in the early 1990s and China is now installing supercritical plant as standard for new plant. There are currently nine supercritical plant in operation in China, with 16 under construction and a further eight planned, althogether totalling over 21GW of coal-fired capacity.

Integrated Gasification Combined Cycle

In integrated Gasification Combined Cycle (IGCC) systems, coal is not combusted directly, but reacted with oxygen and steam to produce a 'syngas' composed mainly of hydrogen and carbon monoxide. The syngas is cleaned of impurities and then burned in a gas turbine to generate electricity and to produce steam for a steam power cycle.

IGCC technology offers high efficiency levels, typically in the mid-40s - although plant designs offering close to 50% efficiencies are available - and as much as 95-99% of NOx and SOx emissions are removed. The further development and support of IGCC offers the prospect of net efficiencies of 56% in the future, and therefore its widening deployment will have an increasingly favourable impact on the environmental performance of coal.

There are around 160 IGCC plants worldwide, including the Tampa Electrik Polk project and the Wabash River coal gasification project in the USA, and the ELCOGAS Puertollano IGCC in Spain. Around 16,500MWe [megawatt equivalent] of IGCC is expected to be operating in the USA by 2020.

The appeal of IGCC technology also extends beyond the potential for increased efficiencies and further reductions in pollutants. IGCC technology may also be the chosen pathway for the ultra low emissions system of the future, using carbon capture and storage, and as part of a future hydrogen economy. In IGCC, the syngas can be 'shifted' to produce CO_2 and H_2, which can then be separated so that the hydrogen is available as a clean fuel product for use in power generation via gas turbines and fuel cells. The CO_2 is then available in a concentrated form for capture and storage.

At present, IGCC applications for power generation are considered by some to be less reliable than other clean coal technology options, such as supercritical PCC and CFBC. Further development in this area will be necessary if the technology is to become the chosen pathway.

Exploiting Synergies with Renewables

Renewable energy technologies are set to grow in importance and account for an increasing share of the world's energy mix. However, there are a number of significant practical and economic barriers that limit the rate of penetration by renewables. The IEA estimates that new renewable technologies will still account for less than 5% of world electricity supply by 2030 [IEA 2002 a].

One of the problems is that renewable energy forms tend by their nature to be intermittent or unpredictable and to be 'site depedent' - i.e. only available at particular suitable sites. Wind energy, for instance, depends on wether and how strongly the wind is blowing and even the best sites do not normally operate for more than about one third of the time. Hydro electric power similarly depends on the right sort of geographic conditions and on rainfall; a dry year may see shortages. Many forms of biomass are seasonal or difficult to transport.

Coal can be used to help overcome these difficulties, and hence support renewables use. Coal is widely available, easy to store and transport, and reliable coal-fired generation can balance the uncertainties introduced into the power grid by intermittent renewable energy. There are also operational synergies between coal and renewables that can significantly increase the efficiency of the renewable technologies and may be the most post-effective way of increasing their use.

In particular, the economics and efficiency of biomass renewable fuels can be improved by co-firing with coal. Existing conventional coal-fired power stations can generally use between 10% and 20% biomass without modification, making it possible to reduce greenhouse emissions and use renewable resources, which would otherwise often go to waste. Purpose-built coal and biomass co-fired plant can also be constructed - fuel crops such as basgasse (sugar-cane), for instance, may be available only on a seasonal basis, making it more practical to construct power plant capable of burning both bagasse (when available) and coal.

Other renewables also offer similar synergies with coal - for instance, linking steam from solar thermal technology with the steam cycle of coal-fired power plant can be an effective way of converting solar energy into electricity, at lower cost and with higher efficiencies than alternative routes, such as photovoltaics.
On a wider scale, coal-fired plant can complement wind or hydro generation providing the back-up needed when the renewable sources are not available.

7. Next generation technologies

For a more detailed discussion concerning CO2 capture and storage see a recent EP study (EP 2003)

CO_2 capture and storage:

The increased efficiencies offered by the state-of-the-art technologies discussed in previous sections offer the prospect of significant progressive reductions in CO_2 emissions from coal-fired power generation over the short to medium term. In the longer term, technologies for carbon capture and storage (CCS) have the potential not only to be an economic and environmentally acceptable route to a low carbon future but also to enable coal to form the basis of a future hydrogen economy.

These technologies enable emissions of carbon dioxide to be 'captured' and 'stored'; that is stripped out of the exhaust stream from coal combustion or gasification and disposed of in such a way that they do not enter the atmosphere. Carbon storage is not currently commercial but the required technologies are already proven and have been used in commercial applications in other contexts.

Development of a "zero-CO_2" coal-fired power plant

The time of development and introduction of the "zero CO_2" power plant is expecte to be determined by permanent storage of CO_2. Despite many R&D projects started worldwide in recent years, the technology is still in an early stage of research even if some field tests have already been completed successfully. In Germany, sequestration in depleted gas fields, deep salt water aquifers and possibly also in not economically mineable coal seams offer favourable conditions for CO_2 storage, as current findings establish. At present, the costs of CO_2 transport and permanent storage are estimated to be some €10 - 24/t CO_2. Necessary fields of research are listed in the German COORETEC concept, and these must be tackled soon in order to qualify and evaluate possible permanent CO_2 storage sites. The research topics range from the detection of suitable geological formations via sealing issues and research into the possible reactions of CO_2 with the site environment all the way to safety and environmental issues. In order to allow a comprehensive evaluation of the overall concept of a "zero- CO_2" coal-fired power plant from an industrial viewpoint, two German based electricity producers (Vattenfall Europe and RWE) participated in an European project on research into CO_2 storage (CO_2 SINK).

Companies, however, are focussing on power plant-related research topics. In principle, for CO_2 capture as well, end-of-pipe technologies, i.e. the separation of CO_2 from the flue gas of conventional fossil-fired steam power plants by means of physical/chemical scrubbing, can be used. However, such process concepts are very expensive and inefficient in energy terms. When CO_2 capture is introduced, it is therefore considered necessary from today's point of view to change to new power generation processes permitting more efficient CO_2 capture.

(See: Engelhard / Ewers / Altmann)

Technologies for capturing CO_2 from emission streams have been used for many years to produce pure CO_2 for use in the food processing and chemicals industry. Petroleum companies routinely separate CO_2 from natural gas before it is transported to market by pipeline. While there is a range of possible capture methods, further development is needed to demonstrate their viability for separating out CO_2 from high volume, low CO_2 concentration flue gases, such as those generated by conventional pulverised coal-fired power stations. If these technical and cost challenges can be addressed, retrofit (or new build) of so-called **'post-combustion' capture** systems will become an economic and practical CO_2 reduction option.
Alternative routes to lower capture costs lie in the production of a more concentrated, pressurised stream of CO_2. This can be achieved through the 'pre-combustion' capture of CO_2 oxyfuel combustion, or through chemical looping combustion.
'Pre-combustion' capture can be achieved via IGCC tehnology by adapting the process so that hydrogen is produced along with CO_2, rather than carbon monoxide. The hydrogen is then combusted in a gas turbine - and in the future used in a fuel cell - and the CO_2 is captured for storage or use.
An alternative approach is **oxyfuel combustion**, which relies on the relatively simple principle of burning coal in an oxygen-rich atmosphere to produce a pure stream of CO_2. Much the same technology is used in steelmaking and hence there may be no insurmountable technical barriers to CO_2 capture linked to oxyfuel power generation in the future.
Another option under development is **chemical looping combustion**, where coal is indirectly combusted via chemical looping. An air-fired boiler uses a continuously looping solid oxygen-carrier, which oxidises the fuel into primarily water and carbon dioxide. Simple condensation of the water then yields a fairly pure stream of CO_2 for compression and liquefaction.

<u>Storing and using CO_2</u>

A number of options for the storage of CO_2 are being researched at the present time, including geological storage and mineral storage.
Geological Storage - Injection of CO_2 into the earth's subsurface offers potential for the permanent storage of very large quantities of CO_2 and is the most comprehensively studied storage option. The CO_2 is compressed to a dense state, before being piped deep underground into natural geological 'reservoirs'. Provided the reservoir site is carefully chosen, the CO_2 will remain stored (trapped in the bedrock or dissolved in solution) for very long periods of time and can be monitored.
An obvious site for geological storage is depleted oil and gas reservoirs. In the USA, it is estimated by the US Department of Energy (DOE) that the storage capacity of depleted gas reservoirs is about 80-100 Gigatonnes, or enough to store US emissions of CO_2 from major stationary sources (e.g. power stations) for 50 years or more.
Saline Aquifers - Storing large amounts of CO_2 in deep saline water-saturated reservoir rocks also offers great potential. One major project is already being conducted by the Norwegian company Statoil. This is at the Sleipner field in the Norwegian sector of the North Sea, where about 1 million tonnes a year of CO_2 are being injected into the Utisira Formation at a depth of about 800-1000 metres below the sea floor.
Another option for permanent CO_2 storage is **Mineral Carbonation** - a process whereby CO_2 is reacted with naturally occuring substances to create a product chemically equivalent to naturally occuring carbonate minerals. The weathering of alkaline rocks is a natural form of CO_2 storage, which normally occurs over long periods of time. Essentially mimicking this natural process, mineral storage speeds up the reactions and turns CO_2 into a solid, environmentally benign

mineral. Mineral carbonation is still at the laboratory stage of development and research is focusing on how to accelerate reaction rates.
While the permanent storage of CO_2 would be the primary goal of geological storage, the practice can have ancillary economic benefits, by enabling improved oil and coalbed methane extraction, which may aid its adoption by industry.
Enhanced Oil Recovery - CO_2 is already widely used in the oil industry to increase oil production - the CO_2 helps pump oil out of the underground strata, so increasing the level of recovery from the field. Without such methods of enhanced production, many oil fields can only produce half or less of the original resource. The CO_2 therefore has a positive commercial value in such situations.
Enhanced Coalbed Methane - is a potential opportunity for storing CO_2 in unmineable coal seams and obtaining improved production of coalbed methane as a valuable by-product.
The capture and storage of CO_2 presents one of the most promising options for large-scale reductions in CO_2 emissions from energy use. The economics of CCS are likely to be broadly comparable with those of other options, such as renewables.

Hydrogen from Coal

One promisign option for the longer term is the move towards hydrogen-based energy systems, in which hydrogen is used to produce electricity from gas turbines and, ultimately, fuel cells.
A key uncertainty surrounding the widespread uptake of fuel cells relates to the availability of hyddrogen, which does not naturally occur in usable quantities. It would therefore have to be manufactured and fossil fuels are one likely source. Coal, with the biggest and most widespread reserves of any fossil fuel, is a prime candidate to provide hydrogen (via coal gasification) in the quantities needed and over the timeframe requirred for the widespread and sustainable deployment of such energy systems. Several countries are starting to implement hydrogen programmes and many of them - Europe, USA, Japan and New Zealand - are considering coal as an option for the production of hydrogen. The European Commission's proposed Hypogen project - a €1.3 billion project to generate hydrogen and electricity produced from fossil energy sources including coal - is one such programme. Similarly, the US DOE FutureGen programme has a declared 10 year timescale to demonstrate hydrogen from coal gasification technology.
To become an attractive option in environmental terms, the production and use of hydrogen from coal would have to be combined with CO_2 capture and storage.

Integrated Gasification Fuel Cells

A hybrid system showing great promise is the integration of gasification with a fuel cell (IGFC). Fuel cells are capable of converting the chemical energy in 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%. They also produce very high-temperature exhaust gases that can either be used directly in combined-cycle or used to drive a gas turbine.
IGFC hybrids have the potential to achieve near zero emissions, with the concentrated CO_2 lending iftself to removal by separation or other capture means. The use of fuel cells has been demonstrated at the 2MWe size and plans are under way to use hydrogen from coal gasification in this and other technologies.

8. R&D Efforts to improve coal fired power generation

This chapter gives only a short overview concerning EU R&D efforts for clean coal technologies (CCT). For a more detailed discussion concerning compatibility of CCT with European R&D policies; see a recent EP study (EP 2003).

In the European Union's Fifth Framework Programme, FP5, (1998-2002), fossil fuel R&D activities were included within a broader energy programme for the development of cleaner energy systems wich was funded at a level of approximately €138 M per year (for the following see: PowerClean 2003).

A major goal of this programme was the deployment of technologies that would permit a 20% reduction of Europe's CO_2 emissions over the next 5-10 years. As such, the objectives included the development and demonstration of a new generation of clean coal technology (CCT) that would improve the ecological and economic acceptability of coal-based power production. Efforts focused on the improvement of conventional coal technologies, on the enhancement of integrated gasification combined cycle (IGCC) plants, on co-utilisation of biomass and coal, and on new processes for the removal of SO_2 and NO_x from flue gases.

In addition to these goals of developing cleaner energy systems, the EU programmes also emphasised the aim of deploying European energy products in the world market and positioning European firms as major competitors in future markets for energy technologies and services. Other programmes promoted the deployment of the new energy technologies, fostered the development and coordination of energy policies among EU member states and between the EU and other countries, and further enhanced energy technology and policy cooperation with developing countries and regions.

Following FP5, the Sixth Framework Programme, FP6 (2002-2006), is designed to further establish a sustainable energy base for Europe. This is to be achieved with an emphasis on the development of renewable energy sources, to the extent that fossil fuel R&D exists only in the context of the capture and sequestration of CO_2. Here the focus is on the development of near-zero-emissions fossil fuel based energy conversion systems, through low cost CO_2 separation systems (both pre- and post-combustion), and through safe, cost efficient and environmentally compatible CO_2 disposal options.

Unless it is countered, this diminution of EU fossil fuel R&D will have unfortunate consequences. If advanced CCTs are not developped and deployed, it will impact adversely on the prospects of Europe meeting its projected energy use targets with a diversified fuel mix while also achieving adequate environmental compliance. This, in turn, will have serious implications for the sustainability of EU security of supply.

At the same time, both from the EU and an international perspective, there will be a reduction in the competitiveness of the EU power generation equipment industry if advanced CCTs are not introduced into their product portfolios, with adverse effects on the economy and on employment. This would be at a time when there are major initiatives in the USA and elsewhere to increase their market share for fossil fuel fired power plants worldwide.

To put this latter point in context, the EU power generation industry is presently comparable in size and employment to the EU IT and aerospace industries, and currently builds close to 50% of the world's power plants.

These issues are considered below and recommendations are made to deal with these sustainability shortfalls through the integration of robust, fossil fuel R&D actitivities within the future EC Framework Programmes.

International R&D projects

Continued improvements in the performance of coal-fired power generation have been made possible by past research and development work undertaken in many countries and involving many organisations, in both government and industry.

Among these projects are:

AD 700 Power Project - Europe

The AD Power Plant involves collaboration between the European Commission and industry and is one of the projects financed by the EU's Fifth Framework R&D Programme. The focus is on establishing ultrasupercritical steam conditions, while at the same time developing improved power plant designs to minimise capital investment. The project aims to raise efficiencies to 55%, resulting in lower fuel consumption and a reduction in CO_2 emissions of almost 15%.

Carbon Sequestration Leadership Forum

The carbon Sequestration Leadership Forum (CSLF) is an international initiative focusing on the development of carbon capture and storage technologies through collaboration. Some 15 countries, plus the European Commission, are involved in the Forum. The inaugural meeting was held in the USA in June 2003 and outlined the Forum's purpose: "To facilitate the development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage: to make these technologies broadly available internationally; and to identify and address wider issues relating to carbon capture and storage". The CSLF is important in that a structure has been put in place, recognising the importance of CCS technologies and their future potential in meeting the environmental challenge of CO_2 emissions from coal-based electricity.

FutureGen - USA

The US$1 billion FutureGen project was launched in 2003 to demonstrate a near-zero emission 275MWe coal-fuelled IGCC plus hydrogen production plant, incorporating CO_2 separation together with geological storage. The project is intended to create the world's first zero-emissions fossil fuel plant which, when operational, will be the cleanest fossil fuel-fired power plant in the world. Cooperation between government, industry and international partners is a key element of the FutureGen project.

Compared with the USA and Japan, the support of coal fired power generation did not play an important role in the EU energy strategy or in the EU R&D policy.

This position is reflected in the strategic priorities of the FP6 where fossil fuel R&D exists only in the context of the capture and storage of CO_2.

In contrast, the EU's major industrial competitors, the USA and Japan, both have long-term visions that include coal and advanced Clean Coal Technologies (CCTs) as a major part of the overall technology mix for a sustainable energy futue. Most importantly, the exploitation of such CCTs within the global export market is seen as a key policy objective. Consequently, when both EU energy/ environmental needs and industrial competitiveness are considered, there is a very real danger that not only will the European Union fail to achieve a sustainable energy future but there will also be a severe and major setback for the EU power generation equipment industry, which could end up severely disadvantaged compared to its major competitors.

It is therefore suggested that there is a need for affirmative action within the EU, including the establishment of a focussed R&D framework programme working towards a vision for EU energy supply and demand, taking full account of all issues including the importance of fossil fuel technologies to EU industry within a global context.

When both EU sustainable energy / environmental needs and industrial competitiveness are considered, it is essential that the case to develop advanced coal based power generation should be a key part of the future EU R&D policy.

Alongside this, the European Union needs to provide an affirmative action to support the EU power industry, to work together on a Europe wide basis to establish the clean use of coal and other fossil fuels, with the aim to ensure near zero emissions power plant.
It is of recommended that the forthcoming R&D Framework Programme (FP7) should include a Fossil Fuel Research Programme (FFRP), for which the emphases should be on

- fuel diversification,
- efficiency improvements,
- emissions reduction,
- improving resource utilisation,
- sustainability.

Such a FFRP should address the main technologies:

- Ultra-supercritical pulverised fuel (AD 700)
- Integrated gasification combined cycle (IGCC)
- Supercritical circulating fluidised beds

Major points of emphasis should include:

- Improvements in efficiency and resource utilisation
- Co-utilisation of coal with biomass
- Near-zero-emissions power production
- Carbon dioxide capture and storage.

There should also be full recognition of the need for large-scale demonstration of the technologies.
Such a programme would address the challenges of the coming decades in a technically viable and economically sustainable manner. It would help to maintain and improve the quality of life for EU citizens, and it would help a large European industry to maintain its competitivity, and consequently employment, in the face of intense international competition.

9. The European Emissions Trading (ET) System: Prospects for Coal

With the launch of emissions trading in Europe, CO_2 will come at a price (for the following see: Schiffer 2004). This means that the price of CO_2 allowances must be factored into the calculations of economic efficiency as an additional parameter. Besides the level of the market price for CO_2 allowances, which will be uniform across Europe in future, economic-efficiency calculations will be impacted by the allocation of allowances by the Member States.

Germany will be taken as an example to describe the working and consequences of the EU ET System. The 2005-2007 National Allocation Plan (NAP) submitted by Germany on 31 March 2004 is divided into a macro-plan and a micro-plan. The macro-plan indicates the total number of allowances to be allocated as well as their breakdown by sector, while the micro-plan outlines the methods, rules and criteria for allocations, as well as the number of allowances for specific plants. This plan provides for the following arrangements:

For existing plants, the basic method underlying the first-time allocation for the period 2005 to 2007 will involve a 100% allocation free of charge on the basis of historical emissions (grandfathering). The actual amount of the allocation is established by multiplying the historical annual average of the emission data (the crucial period is 2000-2002) by a unitary "compliance factor".

New and subsitute plants will likewise receive free emission allowances.

- Where old systems are shut down and substitute plants built, the emission allowances of legacy systems can be transferred to the substitute plants for four years (transition rule). Thereafter, the substitute plants are given free allowances on the basis of fuel-specific benchmarks according to the state of the art for a further period of 14 years subject to a compliance factor of 1.

- The measure for allocations used in the case of new power plants not built to replace existing plants, such as those operated by arrivistes, is in principle an emission value of 750 grams CO_2/kWh. This "benchmark" value is calculated as a weighted average of the emission values for power generation in modern lignite-, hard coal- or gas-fired power plants; it is equivalent to the CO_2 emissions in the power generation of a hard coal-fired power plant with an electrical efficiency of 44%. For power stations having a specific fuel-related emission value lower than 750 grams CO_2/kWh, allocations will not be higher than actual needs, though at least 365 grams CO_2/kWh. This minimum allocation is geared toward the emission value of a modern gas-fired power plant. An appropriately shaped allocation is guaranteds for 14 years subject to a compliance factor of 1.

This allocation plan submitted by the German government offers a facts-driven framework for investing in modern power plants, also on a coal basis. With the passage of the NAP into law and approval by the European Commission, coal is given the perspective it needs for investment decisions in favour of progressive power-plant technologies.

What matters is that, within the scope of any emissions-trading scheme, incentives - e.g. via energy source-unspecific benchmark systems in allocating allowances - are avoided that lead to the replacement of coal-based with gas-fired power plants. The launch of auctioning, too, would one-sidedly favour energy sources low in carbon dioxide, since the operation of coal-fired power plants would require at least twice the number of allowances relative to gas-based power stations.

10. Policy options and recommendations[1]

10.1 Overcoming barriers of implementation of CCT

When a technology becomes economically competitive it may not penetrate its market due to the effects of a range of commercial and institutional factors. Since these factors delay market penetration they are commonly referred to as market barriers. The barriers which are considered most relevant to the heat and power sector technologies are:

Information - Availability of sufficient reliable information to inform decision makers on technology investments.

Risk - Actual or perceived risk associated with the technology and its deployment which may deter investors.

Environment - Actual or perceived environmental impacts of a technology which may restrict its deployment; this would included existing and planned regulations.

Financial- Access to finance to support the deployment of the technology.

Market Character - Some aspects of market operation may bar the deployment of a technology.

Regulation - Regulations which restrict or prevent the deployment of a technology

Infra Structure - The lack of appropriate infra-structure may bar or restrict the deployment of some technologies.

Clear political support - The number of policy makers understanding the need for CCT development might increase but there should be a clear political signal for CCT development support similar to the statement for supporting the development of renewable energies.

Most of the technologies discussed in this module will be affected by more than one barrier at the present time. The main combined effect of these barriers is to penalise the less developed technologies and to impede their introduction into the market. In general terms, pulverised fuel technologies, which are well proven and which are being developed in a progressive manner, face much lower levels of impedance than pressurised pulverised fuel technology, pressurised fluidised bed technology and fuel cells, all of which are commercially un- or at least less proven.

With a consumer-side efficiency increase and alternative energy technology development alone, there is no way that the energy demand in the EU can be satisfied in the next decades. The shut-down of nuclear power plants (with mostly CO_2-free electricity production) as decided for several member states will widen the need for alternative generation facilities and thus increase the need for using conventional fuels. This however will lead to increasing CO_2-emissions instead of reducing them unless the average power plant efficiency can be increased and/or post-combustion CO_2-technologies are applied (which are not yet available).

It is thus not a question to decide between a policy to support an alternative, efficiency increase of CCT, rather we need to follow all options representing the major share of electricity production in parallel with CCT.

10.2 Policy options

Based on the experience from the EESD (Energy, Environment and Sustainable Development) initiative within the 5th EU Framework Programme, the results on CCT should be assessed and

[1] See: EP 2003

efforts should be continued in order to keep the track of security of supply and environmental protection.

- A strong incentive for an EU supported CCT initiative for power plants is the fact that synergies will be created between a technology offensive in clean coal power plant technologies, climate policies, and RTD activities aiming at CO_2 capture and sequestration.
- CCT power plants are complex high-tech products, which integrate diverse engineering disciplines and a broad spectrum of components supplied by main- and subcontractors (mainly SMEs) – the complexity and the supplier/SME aspects are further reasons supporting the concept of a European initiative on CCT power plant technologies.
- An additional driving force towards the initiation of an EU-initiative, project or programme is the need for continuous improvement of their engineering, innovativeness, and efficiency to secure and increase competitiveness of European power plant industries.

Against this background, the EU-initiative shall aim to promote the refinement of low-CO_2-emisson power plants based on CCT in order to:

- fill the expected gap in the power supply security,
- hold the competitive advantage of engineering expertise established within Europe and, thus
- strengthen the potential for industry-backed RTD.

10.3 Conclusions and recommendations

Coal will play a decisive and stabilising role in power production. The advantages of the fuel in combination with the development potential of the combustion/ gasification technology provides the perspective for a reliable, competitive and clean power generation. Due to the increase in efficiency and main process parameters, clean coal technologies can play a significant role for the reduction of CO_2 emissions, considering the specific CO_2 emissions of a fuel in combination with the utilisation rate of the fuel in advanced power plants with supercritical steam parameters with the use of new materials.

The real structural change of the European energy sector is based on the liberalisation of the electricity (and other energy carrier) markets, and secondly on the support of renewable energy technologies. Electricity production facilities have to meet not only the faster changing power demand but also promote short-term solutions with stricter cost-benefit calculations than long-term investments with less calculable risks, even though they might be environmentally more benign. Thus, smaller gas-fired units with short planning and construction periods and lower capital commitments are flexible enough to meet this criterion, despite the higher and less calculable fuel costs, the higher dependencies from a few exporting gas producers, and the more limited gas reserves. Additionally, gas is an ideal fuel for households and smaller decentralised users as complex flue gas cleaning (only economic on a large-scale) is hardly needed.

In contrast, coal offers the advantage of secure supply and prices, but needs more complex flue gas cleaning which is economic for large-scale plants. To get a chance to explore the benefits of high efficient and clean coal technologies for power generation, which are best implemented in larger units, support from the political side is requested to provide the necessary medium- to long term planning security. It is the dilemma that on the one hand political influence to the power sector is contradictory to the basic idea of the liberalisation and on the other hand the need for fast development of the next CCT generation, which meets the efficiency and flexibility demand of the market conditions.

It is important for operators to act in a partnership with manufacturers and politicians in order to obtain the optimum between these requirements and competing targets. Any environmental requirements must consider the market situation: If costs are not covered in the calculable and long-term future by any potential profits, no new power plant will be built. Older, less efficient ones will however be kept in use, or electricity will be imported from countries with less strict requirements. Progress in environmental compatibility must be affordable. Based on market forces, nobody will invest in new power plants and especially new technologies, if they are not able to earn money with them or face un-calculable risks.

All measures mentioned for enhancing efficiency are linked with high capital expenditures. As mentioned, efficiency and environmental compatibility are only two aspects relevant to investors in the power sector. All technical improvements will only be successfully implemented, if they pass the economic criteria. Thus, an increase of efficiency should be linked with a decrease in capital costs.

This is crucial to the power production industry as nobody wants to use a new technology and take all risks on their own. As a consequence, RTD and investments might be delayed in Europe, and in the mid/long-term European manufacturers will lose their leading competence in modern power plants. Research and development capabilities will migrate.

To conclude:

- At latest after the year 2010 there will be a huge demand for new power plant capacity in Europe.
- The main requirement of power plant operators is profitability and high competitiveness. This requirement must be obtainable or further support from the EC will be needed to overcome at least any initial barriers. Furthermore, the power plants must be flexible in operation as required by conditions for a competitive, liberalised power market.
- The development of power plant technology should be done in a consortium of manufacturers, operators and research institutes. Due to the technical and economic risks, public subsidies as well as governmental policy support are necessary.
- In today's outlook, new and highly efficient coal fired power plants meet these requirements best in the short-to-mid term. They offer the greatest potential for closing the forecast shortage of energy supply and allowing a parallel decrease of CO_2 and other emissions if old power plants are replaced by power plants in the 45% (today) to >50% (in some 5-15 years) efficiency range.
- In the longer term, technologies allowing for (nearly) CO_2 emission free power plants need to be developed. These technologies are rather based on previous coal gasification or combustion with oxygen rather than air, as they allow CO_2 sequestration with a higher overall efficiency (or better, less reduced: minus 6-8% instead of minus 10-12% or more for advanced PCF-based CCTs). As these technologies are **not** competitive on the market, public support is needed to start or continue any R&D initiatives on larger scale.
- Any CO_2 capture is pointless if no sufficient and reliable CO_2 storage options are available. Thus, in parallel to CCTs with CO_2 capture, CO_2 storage technologies also need to be developed. Under liberalised market conditions, this is again not a task promoted and financed by CCT developers and manufacturers, at least not alone. Public support in RTD as well as policy development is essential.

Preventive climate protection and sustainable rationing of scarce resources will be obtained by innovative and competitive power plants.

The further development of Clean Coal technologies will not only contribute to any environmental impact but will also increase the export chances of the European power plant manufacturing industry. Developing countries in particular will cover their increasing power demand mostly with coal. The IEA in Paris forecasts a tripling of the share of coal fired power plants in these countries by 2030. If European manufacturers alone would be positioned to (further) support China and India, which will have an extremely fast increase in power demand for the extension of power plant capacities with the latest technologies and operational know-how, there would also be a boost in the application of CCT in Europe and it would open new markets for European industry.

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