




# Issue Brief

## COAL

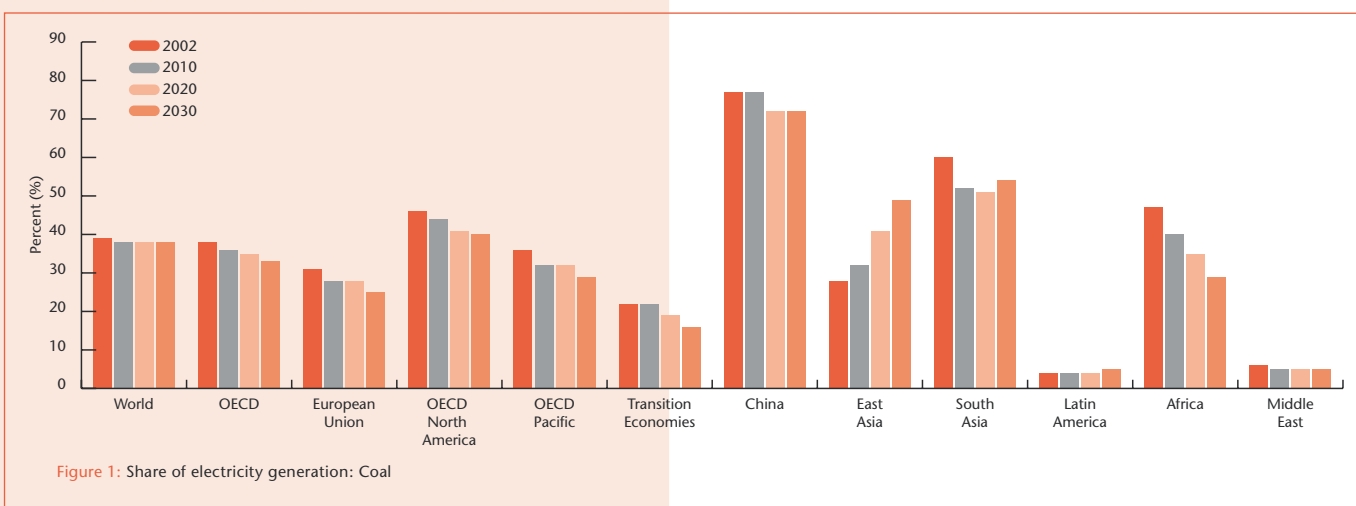
### SHARE OF ELECTRICITY GENERATION

More electricity is generated from coal than from any other fuel. In 2002, coal was responsible for 39% of worldwide electricity generation. It is projected that coal will remain a major source of electricity generation over the next 25 years, with its world share remaining above 35%. To meet growing energy demand, a very large number of new plants will be required. Projections are that current capacity will be doubled over the next 30 years, roughly equivalent to the net addition of 1,000 large (1,000 MW) plants.<sup>1</sup>

Coal is an important source of generation in Africa, Asia, Europe and North America. The envisaged role of coal

for future electricity supply varies by country and region, depending on reserve accessibility and extent, current share of the energy mix, energy security policy, emissions regulations and agreements (including the Kyoto Protocol), and the size and future viability of the indigenous coal industry.

Coal's share of power generation in industrialized countries is currently between 20% and 45%, with gradual decreases projected for the coming decades depending on the availability of competitively priced alternative oil and natural gas reserves.



In developing Asia coal plays the most significant role in electricity generation. In 2002, coal accounted for more than 60% of electric power generation in South Asia and almost 80% in China. Asia is expected to be one of the largest sources of growth in electricity demand over the next 30 years, and coal is projected to be the key source to meet this increase. China is currently constructing on average more than one plant per week.<sup>2</sup> While a few governments are taking steps towards phasing out coal (e.g., Ontario Province in Canada), others see it continuing to play an important role in the future energy mix.

## RESOURCE AVAILABILITY

Coal is the most abundant and widely spread fossil fuel resource worldwide. There are over 200 years of economically recoverable reserves available using current mining technologies and at current extraction rates.<sup>3</sup> This is far in excess of reserves of oil or natural gas, whose demand is expected to peak during this century. A well-developed world trading system transports coal around the world, principally by ship, but only one-sixth of all coal is currently traded between regions.<sup>4</sup> Trade levels are growing, but the vast majority of coal is used within the region in which it is produced.

Coal is not homogenous: it ranges from high-rank anthracite ("hard coal", with a very high carbon component) to low-rank "brown" coals, which contain high proportions of water. The carbon base of coal can be contaminated with non-combustible minerals and other impurities, leading to lower quality. The energy content per metric ton of low-quality coal can be two-thirds lower than the highest quality coals. Coal is bulky and, over long distances, transport costs become significant. This leads to three main effects:

1. Only the highest quality coal tends to be traded internationally;
2. Low-quality coals must be used close to where they are produced – their transport costs per unit of energy produced are otherwise prohibitive;
3. Transportation costs impose a limit on how far coal can be transported over land. Coal resources in locations far from coastlines are not traded around the world.

Coal production is thus dependent on quality and location rather than the size of reserves alone. Australia, Canada and the US all have high-quality coking coal (a key input to iron & steel production); Australia, China, Colombia, India, Indonesia, Russia, South Africa and the US have very large reserves of steam coal (suitable for power plants).

Transportation costs exhibit regional variations but are already a significant part of traded coal costs and are likely to increase as trade increases in the future to meet heightened world demand.

## CURRENT TECHNOLOGIES

Over 90% of coal-fired electricity generation comes from conventional pulverized coal (PC) combustion technology.<sup>5</sup> This technology, first developed in the 1920s and put into widespread use worldwide in the 1960s, involves "pulverizing" coal into tiny fragments (generally less than 0.1 mm across) and then mixing these fragments with air. This mixture is then injected into a boiler where it behaves very much like a gas and burns in a controlled manner. PC units are generally at least 300 MW in size<sup>6</sup> with a cost approaching US\$ 1,000/kW.<sup>7</sup> The capital cost for conventional coal plants is higher than natural gas combined cycle gas turbines (CCGT) but lower than other options (nuclear, hydro, renewables, etc.).

Conventional "old generation" PC systems are "subcritical" (meaning that they operate at relatively low steam pressure). Their efficiencies range from 33-39%. The following factors tend to result in lower thermal efficiency:

- Low quality and higher moisture content coals;
- Dry (air) cooling rather than water cooling (typical efficiency losses are 1-3%, with higher losses as the ambient temperature increases);
- Flue gas desulfurization (FGD – typical efficiency loss 1-2%).

Even in the lower range of thermal efficiencies, coal-fired generation from existing plants is generally one of the lowest cost electricity generation options because of the low cost of coal. The availability of low cost natural gas in certain parts of the world during the 1990s made natural gas CCGT the technology of choice for new plants, but rising prices have largely eliminated the cost advantage of gas. The choice of a base load plant is now much more uncertain, with significant local variations caused by access to (and hence prices of) coal and natural gas.

In areas where coal prices are high and/or emissions legislation is conducive, retrofitting existing PC plants with more efficient turbines and boilers can raise efficiency by a few points and prolong a plant's lifetime. Where demand is growing strongly (e.g., China and India), the option is not often used – the loss of supply due to downtime during the retrofit is too important.

## TECHNOLOGIES GOING FORWARD – “ADVANCED COAL” AND “CLEAN COAL”

The principal challenge to coal generation is its environmental impact rather than its economics. A wide range of technologies is at various stages of implementation. Compared to conventional PC, they can offer significant improvements in efficiency (lowering emissions and costs per unit of electricity generated) and/or reduce emissions of NO<sub>x</sub>, SO<sub>x</sub> and particulates (the three major causes of local and regional air quality problems). Technologies, which reduce emissions compared to conventional PC, are often referred to as “advanced coal” and “clean coal”.

*Advanced coal* options include supercritical PC plants that operate at higher steam pressure than conventional plants. These systems offer higher efficiency than their conventional counterparts, admittedly at higher cost. Supercritical plants are proving their worth in the market: 85% of PC boilers between 1997 and 2000 were supercritical,<sup>8</sup> and China is planning to install locally manufactured supercritical boilers on a large scale.

*Clean coal* technology mainly refers to integrated gasification combined cycle (IGCC), and to a lesser extent to fluidized bed combustor (FBC). These systems have been demonstrated and commercialized respectively on a large scale. However, their capital costs are higher, and this is a significant barrier to the implementation of Clean Coal in the key markets of China and India and in many other markets in the developing world where the available tariffs may not support a higher capital investment. A further barrier is that IGCC technologies are not yet fully “proven” in commercial conditions.

The three key advanced and clean coal technologies are:

1. PC supercritical and ultra-supercritical;
2. Fluidized beds;
3. Integrated gasification combined cycle.

Coal generation could follow a chain, for example PC supercritical then PC ultra-supercritical and finally IGCC.

### PC supercritical and ultra-supercritical

Raising the pressure and temperature of the steam produced using supercritical cycles can increase efficiencies to 45%, with an eventual 50% postulated. A number of supercritical plants have been successfully commissioned, mainly in the US, the former Soviet Union and Italy. More recently (in the past 10-15 years), Denmark, Germany, Japan and South

Korea have constructed plants, but China is seeing the largest construction rate today.

*Ultra-supercritical* plants are expected to be available within a decade, raising efficiencies above 50%. Compared with conventional PC plants with thermal efficiencies in the mid-30% range, ultra-supercritical plants have the potential to significantly reduce CO<sub>2</sub> emissions per unit of power produced.

### Fluidized beds (subcritical and supercritical)

Fluidized beds offer several advantages over pulverized fuel combustion, notably:

- Low NO<sub>x</sub> emissions;
- In-process capture of SO<sub>2</sub> with limestone;
- The ability to burn a wide range of low-grade and potentially difficult fuels (including waste and biomass) as well as mixed fuels.

The “conversion” (combustion or gasification) of solid fuels for production of heat and/or electricity can be done by various fluidized bed techniques (usually “bubbling” or “circulating”) working at atmospheric pressure or under pressure. Supercritical steam conditions can be used for fluidized bed boilers (atmospheric and pressurized) in the same way as for PC boilers. Electricity generating efficiency in the range of 45% may be attained in the near future.

Circulating fluidized bed boilers entered the utility market in 1985 with the successful operation of the world’s first reheat CFB boiler installed in Germany. They are now progressing steadily with large coal-fired units in the 250-300 MW range being installed worldwide.

Current R&D on fluidized beds is concentrated mainly on low (atmospheric) pressure systems, due to their ability to combust difficult fuels such as biomass (either as a sole fuel or co-firing with coal). The development of plants will depend on increasing unit capacities (sizes currently range up to 300 MW) and incorporating supercritical steam cycles to increase efficiencies towards 45%. Emissions will be reduced but the technical problems remain challenging.

About ten demonstration PFBC (pressurized fluidized bed combustion) units have been built worldwide since 1990, half of them in Japan with the largest, a 360 MW, installed in Kyushu. Market penetration is modest: utilities have adopted a cautious approach due to the higher costs and complexities of PFBC compared to competing technologies.

## Integrated gasification combined cycle

IGCC first involves “gasifying” coal (converting combustible material to gas phase), and then using these gases, after cleaning, as the fuel for a combined cycle system. Gasification processes have been used for many years, for example in chemical plants and particularly in refineries, for co-production of hydrogen and, with methanol, “syngas” and other chemicals. IGCC remains a chemical plant in nature, making it more difficult to follow changes in electricity load.

The challenge is to build an entire power generation system to run downstream of the gasification process. IGCC systems (without CO<sub>2</sub> separation) are being demonstrated, including three plants in the US and plants in Spain and the Netherlands. However, there has been virtually no market penetration due to the high cost.

Recently, there has been greatly renewed interest in IGCC technology because it may be more practical and cost effective to separate and capture CO<sub>2</sub> from the high-pressure, high CO<sub>2</sub>-concentration gas stream prior to combustion in an IGCC plant, than from other systems. CO<sub>2</sub> capture is challenging in other combustion systems because the CO<sub>2</sub> is formed in the combustion process, and the exhaust stream is low pressure with low CO<sub>2</sub> concentrations (due to the combustion air). Oxy-combustion PC or FBC offer similar opportunities for relatively easy CO<sub>2</sub> separation.

IGCC plant efficiencies could be in the range of 45%, although improvements in turbines could increase this to over 50%. Large-scale demonstration units are operational or under development in many countries across the world (Europe, Canada and Australia, with the largest program being the US\$ 1 billion the US is planning to spend over the next decade on its FutureGen Initiative). A number of utilities have announced plans to install “capture-ready” coal plants (incorporating the valves and other controls which would be needed to capture CO<sub>2</sub> at some later date); the commissioning of the first “capture-ready” plant has been announced.

One novel application is *Underground Coal Gasification (UCG)*, where coal is gasified directly in the coal seam. This has been in commercial operation in the former Soviet Union since the 1950s and experimental trials have subsequently been performed in many other countries, including the USA, UK, France, Spain and Belgium. The Chinchilla pilot plant trial in Australia was initiated in 1999 and is the largest

outside the former Soviet Union. A pilot plant is presently under construction in South Africa, and if successful will lead to an installation that will supply 1,200 MW of electricity generating capacity by 2009. There are presently also UCG feasibility studies underway in the UK, the USA, India, Pakistan, Sardinia, Australia and New Zealand. UCG can be competitive with conventional mining technologies, and is particularly suited to seams that are deep, thin, low-grade or inclined. It can be expected that UCG with a combined cycle gas turbine (UCG-IGCC) or for coal-to-liquid (CTL) plants will gain prominence in countries with limited access to fossil fuel sources such as oil and natural gas, or when these have passed their peak production.

## IMPACTS

In the longer term, the use of coal is threatened by its environmental impacts: emissions of local pollutants and greenhouse gases, and ash disposal, both represent major challenges. On a per unit electricity generated basis, conventional “old generation” coal plants (subcritical pulverized coal) emit up to twice as much CO<sub>2</sub> as natural gas combined cycle (CCGT). New generation coal plants (ultra-supercritical pulverized coal and UCG-IGCC) will reduce coal emissions to only 50% higher than natural gas CCGT. Coal plants still emit ultra-fine particulates, trace elements and SO<sub>2</sub> (which are negligible for natural gas). The NO<sub>x</sub> emissions of natural gas plants are only marginally better than conventional coal plants, but are higher than emissions from new generation coal plants.

## Environmental – Global

The combustible portion of coal is chemically almost pure carbon and thus, per unit of energy contained, it liberates the highest quantity of carbon dioxide emissions of any fossil fuel. With “old generation” coal plant emitting up to twice as much CO<sub>2</sub> as natural gas CCGT, carbon prices from greenhouse gas (GHG) emissions reduction schemes would increase the cost of generation from existing coal plants by twice as much as from existing natural gas plants (CCGT).

The use of coal for power generation contributed 70% of worldwide CO<sub>2</sub> emissions from power generation in 2002 (and approximately 28% of CO<sub>2</sub> emissions from all combustion sources). It is projected that this share will decline marginally to 68% in 2030, due to the projected rapid expansion of natural gas capacity.<sup>9</sup> In the short to medium term, several initiatives are underway to increase the efficiency of coal generation, thereby reducing the amount of GHGs emitted per unit of electricity generated. In the

longer term, carbon capture and storage offers the potential to capture the majority of CO<sub>2</sub> emissions.<sup>10</sup> Climate-related policies and regulations could have a significant impact on the competitive position of coal plants and other coal-related assets.

## Environmental – Local

Table 1 summarizes the major impacts caused by the release of pollutants during coal generation. Coal generation is not the only source of these pollutants, but for SO<sub>x</sub> and particulate matter, is often a major source, particularly close to generation plants. Certain components such as carbon monoxide are only released in minor proportions (parts per million) during normal operation, and other components such as trace elements are entirely dependant on the coal's composition, and to a lesser extent on combustion plants and their operation.

The *level of impurities* varies markedly, e.g., low sulfur coals contain less than 1% sulfur, whereas high-sulfur coals can contain over 2%; high-quality coals contain less than 5% of minerals, whereas some coals contain over 50%; water content also varies widely, with higher levels making coal more difficult to burn and hence reducing efficiency.

Electricity can be generated from coal without significant cost to health. Coal plants with modern controls meet environmental regulations for NO<sub>x</sub>, SO<sub>x</sub> and particulate emissions in the most demanding countries. Such plants are installed as a matter of course in the developed world. A range of *emissions abatement technologies* can be applied at various points in the plant:

- Particulate emissions can be reduced by approximately 99% through the operation of well-maintained, relatively simple technologies such as fabric filters, wet particulate scrubbers and electrostatic precipitators (ESPs). These technologies are applied to the exhaust gas.
- Emissions of SO<sub>x</sub> can be reduced by more than 90% with flue gas desulfurization (FGD) technology, or in-bed sorbent injection in the case of fluidized bed combustion (FBC). In many parts of the world, desulfurization is required for all new coal plants. FGD prices are now of the order of US\$ 80-200/kW.<sup>11</sup>
- The majority (50-80%) of NO<sub>x</sub> from coal plants comes from the nitrogen present in the coal (fuel bound nitrogen) rather than from the oxidation of nitrogen present in the air. A wide range of technologies and techniques are available to reduce NO<sub>x</sub> emissions, principally during combustion, including: burner

optimization (15% NO<sub>x</sub> removal); over-fire air; flue gas recirculation; fuel staging; and low NO<sub>x</sub> burners). NO<sub>x</sub> can also be taken from the exhaust gas using selective catalyst (SCR, 80-90% NO<sub>x</sub> removal) or non-catalyst reduction (SNCR, 30-50% NO<sub>x</sub> removal) and in combined SO<sub>x</sub>/NO<sub>x</sub> control systems.

The key problems are:

- In some parts of the world, many older plants and some newer plants operate without emissions controls, and dry ash may be left exposed to wind where it can be blown away;
- Methods for abating emissions of toxic metals (notably mercury) are yet to be fully developed and implemented.

How ash is handled is critical. Coal combustion generates huge quantities of ash (depending on the fraction of non-combustible minerals in the coal). Ash may contain a number of harmful compounds (e.g., heavy metals) and requires proper handling. Improper handling of ash can produce air pollution, air toxics, and water and land contamination.

## Social/Community

Coal-fired power plants, and the associated needs for coal mining and transport, are labor intensive. Large communities can build up around coal facilities, and their closure can produce large-scale unemployment. Community members often have few skills that can be easily transferred. Partly for this reason, many governments have subsidized their coal industries in the past (although this support has been largely for coal mining and is generally decreasing).

Mining can have major environmental and social/ethical impacts. Mine safety is a key social issue in the coal industry, and providing the means to set up good governance to improve security in mining facilities must be made a key priority worldwide.

New coal-fired power plants can transform the economies of lightly developed regions. The electricity they generate is in many cases the only cost-effective route towards large scale electrification for communities without access to hydro power resources or to large quantities of other fossil fuels. New power plants often bring roads, schools – and electricity – to their immediate surroundings, to the extent that these may be lacking.

Pollutant	Source	Impacts
NO <sub>x</sub> (nitrogen oxides) gas/aerosol	Principally from the oxidation of nitrogen in coal, with some oxidation of nitrogen in the air	<ul style="list-style-type: none"> <li>Respiratory problems and disease</li> <li>"Acid rain", erosion of buildings and damage to lakes, forests and crops</li> <li>NO<sub>x</sub> is a precursor of ground level ozone formation, which adversely impacts all living matter</li> </ul>
SO <sub>x</sub> (sulfur oxides) gas/aerosol	From the oxidation of sulfur in the coal (which typically ranges from under 0.2% to over 2%)	<ul style="list-style-type: none"> <li>Respiratory problems and disease</li> <li>"Acid rain", erosion of buildings and damage to lakes, forests and crops</li> </ul>
Carbon monoxide (CO)	Formed from the incomplete combustion of carbon in the coal	<ul style="list-style-type: none"> <li>Inhibits the ability of blood to transport oxygen around the body. The body can fully recover if exposure does not cause any damage</li> </ul>
Toxic metals (mercury, vanadium, etc.)	Various toxic "heavy" metals are contained in coal, depending on its source	<ul style="list-style-type: none"> <li>Severe health impacts (depending on exposure and on the metal and the form in which it is released)</li> </ul>
Particulates	The majority are formed by non-combustible materials passing through the coal plant and being released as small particles. Some particulates are also created by combustion	<ul style="list-style-type: none"> <li>Particulates can have a severe impact on the respiratory system. Very small particles such as PM<sub>10</sub> (particulate matter no larger than 10 microns across) are particularly damaging as they can penetrate deep into the lungs</li> </ul>

Table 1: Local impacts from coal generation

## RESEARCH & DEVELOPMENT

In the short and medium term, R&D activity is focused on *cleaner coal*, *advanced coal* and *clean coal* technologies. In the near future (to 2015), these aim to:

- Increase efficiencies to 50%;
- Reduce emissions of air pollutants to near zero;
- Develop plants compatible with carbon capture and sequestration;
- Reduce capital costs of plants.

By technology, targeted activities can be categorized as follows:

### Cleaner Coal

- *PC subcritical*. Develop techniques to optimize performance, particularly lowering emissions of NO<sub>x</sub>, SO<sub>x</sub>, particulates and a range of trace elements and compounds. Develop methods for burning low-grade coals cleanly and cost-effectively. Find more cost-effective ways of waste disposal with lower environmental impacts.

### Advanced Coal

- *PC supercritical and ultra-supercritical*. Continue to develop demonstration program. Develop new generation materials (e.g., high temperature steels) for increasing steam temperature and pressure (and hence increasing efficiency to 50% and beyond).

### Clean Coal

- *Fluidized bed combustion (FBC)*. Build up from commercialization. Increase efficiencies to 45% with the use of supercritical steam conditions. Raise unit capacity by investigating techniques for constructing boilers larger than 600 MW with compact design and less refractory. Improve fuel handling, by-products utilization and ashes and residue characterization.
- *Integrated gasification combined cycle*. Further demonstration is needed to increase confidence and decrease costs to those of current PC plant. Current and future R&D activities are focused widely, e.g., reliability/availability, refractories, syngas cooler material and deposition, coal feeding, coal conversion, co-gasification, dry gas desulfurization, scale-up costs of hybrid cycles. Underground coal gasification (UCG) forms part of this

family of technologies, and offers potential to simplify the process and reduce costs further.

Due to the large scale of coal generation technologies, R&D collaboration between plants and equipment manufacturers and generators, with support from research institutions and governments, is common. Government support is often needed as many of the activities involve significant financial and technical risks. Many countries have strategic clean coal programs (US, EU, UK, Australia, Japan, Germany). There are several companies and industries that are also pro-actively pursuing new coal technologies without national support. Examples include Tata Iron and Steel in India with their FBC plant to consume discard coal waste streams from their mining operations, and Eskom in South Africa with their UCG pilot plant. Recent announcements of new IGCC plants to be built in the US are also encouraging and indicate a growing change in overcoming past obstacles.

The longer-term aim of R&D is to develop near-zero emissions technologies, with emissions reductions going far beyond efficiency improvements from existing plants. These would be compatible with CCS (Carbon Capture & Storage), a promising “end of pipe” technology for eliminating most of the CO<sub>2</sub> released during coal combustion. Other CO<sub>2</sub> reduction options include co-firing or gasifying coal with biomass, potentially in combination with wastes and/or biomass, and steam to produce hydrogen and other fuels for fuel cells.

A key requirement for reducing the impacts of world coal generation is the transfer to the developing world of the best technologies available today and of those that will reach the market in the future.

## REFERENCES AND NOTES

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- 5 International Energy Agency, Clean Coal Technology database, <http://www.iea-coal.co.uk/site/database/cct%20databases/cct%20home.htm> (last accessed 18 June 2004).
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Our **mission** is to provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues.

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