COAL OF THE FUTURE

(SUPPLY PROSPECTS FOR THERMAL COAL BY 2030-2050)

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ARA……………………………………………………..Amsterdam-Rotterdam-Antwerp
BBS……………………………………………………...Borehole-to-Borehole Seismic
BFBC…………………………………………….Bubbling Fluidised Bed Combustion
CBM……………………………………………………………Coal Bed Methane
CL……………………………………………………………...Caving Longwall
CCGT…………………………………………………Combined Cycle Gas Turbine
CCS………………………………………………………..Carbon Capture and Storage
CCT…………………………………………………......Clean Coal Technology
CFBC……………………………………………….Circulating Fluid Bed Combustion
CMM……………………………………………………………..Coal Mine Methane
CSIRO………………… Commonwealth Scientific and Industrial Research Organization
CTL……………………………………………………………..Coal-to-Liquids
CUMT……………………………………Centre for Underground Mining & Technology
CV……………………………………………………………….Calorific Value
DIGHEM…………………………………………..Digital Helicopter Electromagnetics
DTI………………………………………………..Department of Trade and Industry
EERC……………………………………….Energy & Environmental Research Centre
EOR…………………………………………………………Enhanced Oil Recovery
FBC……………………………………………….........Fluidised Bed Combustion
FOB……………………………………………………………………Free on Board
GAD…………………………………………………………………Gross Air Dried
GTCC……………………………………………………Gas Turbine Combined Cycle
GTL…………………………………………………………………Gas-to-Liquids
HEM…………………………………………………….Helicopter Electromagnetics
HM……………………………………………………………….Hydraulic Mining
IEA…………………………………………………..International Energy Agency
IGCC……………………………………………Integrated Gasification Combined Cycle
IMO…………………………………………….....International Maritime Organization
LRC…………………………………………………………………… Low Rank Coals
LTCC……………………………………………………Longwall Top Coal Caving
MSL……………………………………………………………Multi-Slice Longwall
NG……………………………………………………………………...Natural Gas
PF……………………………………………………………………..Pulverized Fuel
PCFBC…………………………………… Pressurised Circulating Fluid Bed Combustion
PFBC……………………………………………..Pressurised Fluid Bed Combustion
SPL…………………………………………………………..Single-Pass Longwall
TRD…………………………………………………………..Tight Radius Drilling
UCG……………………………………………………… Underground Coal Gasification
VAM……………………………………………………...Ventilation Air Methane

1 EXECUTIVE SUMMARY

This report assesses the prospects for thermal coal supply over the 30-50 year horizon primarily by examining at the markets and technologies that will be able to supply Clean Coal Technologies (CCT's). CCT's are classified essentially into two broad categories:

- Technologies which improve burning efficiency and reduce emissions, including integrated gasification, higher efficiency Pulverised Fuel (PF) combustion, fluidised bed combustion, and coal washing.
- Technologies which fundamentally change the way coal is used to create energy, including various gasification and liquefaction technologies.

Right now, about 98% of the power generated worldwide from coal comes from low thermal efficiency (about 35%) PF combustion. In order to capture more market share, CCT's must be able to utilize coal stock in a wide variety of qualities as defined by Calorific Value (CV), ash and sulphur content, volatile matter content, etc.

It is unlikely that significant coal resources remain undiscovered. Revolutionary new techniques for better mapping of known resources are not developing rapidly, due to the traditionally moderate return on investment for coal production. Current or nascent technologies which should allow for improved mapping of resources include Helicopter Electromagnetics (HEM) to enhance aerial surveying, improved drilling techniques, new seismic mapping efficiencies, and database management techniques.

Whilst productivity in terms of tonnes per man per year is generally improving, it is interesting to note that average production costs across countries are reasonably similar, regardless of the individual countries' typical labour productivities, suggesting that such productivities are not the only drivers of costs. Other important factors are mining techniques, essentially variations on opencast and underground mining. Generally, opencast mining is more productive than underground mining and, with new operations in developing countries coming online, it is estimated that opencast will grow to about half of production in the future. It is believed that opencast mining is currently functioning at its highest possible productivity; underground techniques, however, especially bord and pillar and longwall mining, will probably gain in productivity from dissemination of existing technical innovations.

Coal Mine Methane (CMM), or the methane in coal seams liberated during mining, is a promising potential source of energy. However, estimated attainable reserves are significantly smaller than those attainable from coal, making CMM projects more interesting in terms of their carbon abatement potential. For many sources of CMM, the marginal costs of abatement are extremely low – often in the neighbourhood of \$3/tonne CO_2 abated - making projects attractive in an environment where carbon credits are traded at \$5 - \$30/tonne CO_2.

Underground Gasification of Coal (UCG) is the gasification of coal where it sits in the ground, and, as such, avoids many of the expenses and disadvantages of traditional mining, whilst generating a fuel with a lower emissions profile potentially similar to that of natural gas. The ratio of worldwide inferred to proven mineable coal resources is about 6:1, indicating that the potential increase in recoverable resources using UCG is enormous, with a total gas volume estimate on the order of 6,900 Tcf.

Freight markets are essentially determined by the balance between ship sizes and abilities and the demand for tonnage. When the ship market is oversupplied compared to the freight to be moved, the cost is defined by the cheapest ships – the oldest, with fully depreciated costs. However, the market moves quickly as this will establish a new, lower freight rate. Although the market is driven by short-term factors and is very difficult to predict beyond five years, the general trend for new builds seems to be towards larger-sized vessels – so-called Panamaxes and Capesizes – and facilities. It is projected that in the near-to-mid-term, available tonnage will move back towards equilibrium with the recent boom in iron ore demand, bringing shipping costs down to more historical levels, adjusted for structurally higher fuel costs.

Overall, the behaviour of power markets is the most powerful driver of coal demand, followed by political and social drivers reflecting the need to reduce carbon emissions. Worldwide, it is expected that energy demand will grow in line with GDP – with a 2.5% annual growth rate in Asia and a 0.5% rate in the developed countries – through 2050. To meet this demand, gas is expected to increase its global market share to 34%, with coal expected to be at slightly above 20% (for power generation, up to 40%), with more than 70% of this to be provided by CCT's.

The coal export market should continue to be tight and to be pulled by demand for coal with higher thermal values. This report breaks countries and regions down into 4 tiers, depending upon how they are impacted by availability of coal imports:

- Tier 1, Self-sufficient or better: Essentially North America and Russia
- Tier 2, Prime exporters: Australia, Colombia and Indonesia
- Tier 3, Able to meet domestic demand: India
- Tier 4, Facing potential shortfalls: China and much of Europe

For Tier 3 and 4 countries, it is likely that the utilization of new technologies, including CCT's, as well as the exploitation of lesser thermal grade sources/coal with high ash content will be important for meeting their needs.

2 INTRODUCTION

This report examines the coal[1] markets that are capable of supplying coal for new clean coal technologies (CCT's) and the impact on coal markets. It is true to say that coal has enjoyed something of a renaissance in recent years and international coal prices are at historic highs primarily because suppliers have little capacity to meet increased demand. There is a growing interest in CCT and a strong belief that coal can meet much of the world's energy needs if it can be used in a way that minimises emissions and exploits coal resources that are unlikely to be mined by conventional techniques

Although coal is considered to be the most abundant of the fossil fuels, its reserves are not limitless, especially when historic economic factors are considered that suggest coal fed to mine-mouth or nearby power plants should be produced at under $30[2] cash cost or export coal at $30 Free on Board (FOB).

Coal demand is projected to rise consistently through to 2030 at least when the development of certain clean coal technologies may see a change in the way coal is used. However, if CCT advances quickly – at least quicker than the progress over the past two decades – there is a possibility that traditional coal supplies may not be able to cope with significantly higher demand.

This is because not only are coal resources limited but they are often located in areas where energy demand is not high – Australia, South Africa, Colombia and Indonesia, for example. This means not only that coal supplies have to meet market demand but infrastructure – rail systems and loading and discharge facilities – have to be adequate. At present, there is little spare capacity in these areas, just as there is little extra capacity in the world bulk carrier fleet.

This report looks at CCT's and the type of coal suitable for them, together with an assessment of coal supplies to meet world requirements in conventional technologies. There are no reliable projections of long term CCT-driven demand because there is no clear business case for many of the technologies in terms of likely implementation.

The report also looks at the potential for coal to be exploited in a more environmentally benign way, including the use of coal mine methane (CMM), which is both an energy source and a means of reducing greenhouse gas emissions, and the production of energy through underground coal gasification (UCG), which has the potential to increase the energy reserve base of coal while producing a product which may be less carbon intensive than conventional coal production and consumption.

The report also assesses key drivers of coal markets and discusses their role in future markets.

[1] Coal references in this report concern thermal coal and do not include coals used in steel-making processes
[2] Unless stated, all references to $ are US dollars

3 CLEAN COAL TECHNOLOGIES (CCT'S)

CCT's can be divided into two broad areas:

- Improving coal burn characteristics and reducing emissions during the burning process
- Using coal in other ways that fundamentally change the way its energy is exploited, as in gasification and utilisation.

There is approximately 5 billion tonnes of hard coal used in the world annually, with a further 1 billion tonnes produced as lignite. The majority (over 80%) of the hard coal produced is steam or thermal coal.

About 70% of the total thermal coal produced in the world is used in power generation, almost all of which uses pulverised fuel (PF) technology. Certain countries are particularly dependent on thermal coal supplies:

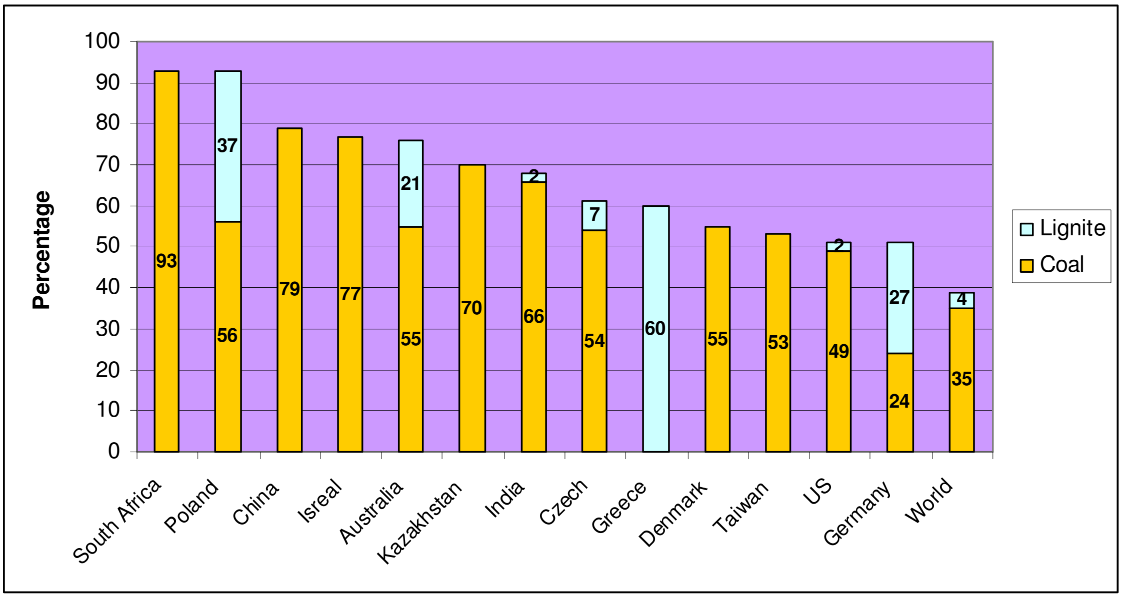


DIAGRAM 1 – Contribution of coal to power generation

Source: RWE

The first point about CCT is that there is a surprising range of coal quality available in both traded and local markets. In internationally markets, typical coal qualities range as follows:

▪ CV (kcal/kg GAD)	5500-7500
▪ Ash (%)	6 -18
▪ Volatile Matter (%)	15-35
▪ Sulphur (%)	0.1-1.50
▪ Fixed Carbon	40-70

This implies that there are coals for a range of applications and the type of coal can have a significant impact on boiler performance. International coal is still largely traded based on the heat value. Ash, sulphur and other potential contaminants are important and will become more so, but at present the heat value remains the fundamental value definer. It is interesting to note that the lowest heat value coal commonly traded is from PT Adaro from Indonesia. The coal is a sub-bituminous product

The CCT's can be summarised as:

3.1.1 Coal washing and beneficiation

One of the simplest and best-known techniques for reducing emissions is the washing of coal. In many ways, South Africa leads the way in such technology as the coals mined in the country are poorer quality and require cleaning to be exported. The coals in South Africa are slightly younger than those of the Northern Hemisphere (Permian age as opposed to Carboniferous) and, crucially, were formed in cold conditions compared with the tropical conditions of the northern hemisphere. This results in a lower vitrinite content and a inherently lower quality. Beneficiation by coal washing in a dense medium bath allows an acceptable export quality to be made whilst local power plants are designed to use coal with low CV and ash contents of up to 50%.

South African producers have passed through a long evolutionary process in coal beneficiation. Producers have seen the gradual increase in coal washing in order to maximise revenue. Originally large coal was picked for sale and the duff (small coal) was discarded. Gradually the coarser coal would have been cleaned in jigs and later dense medium. As user technology developed coal had to be washed down further, down to 1mm, in jigs and then dense medium cyclones. In South Africa, fines only began to be cleaned in spirals in the early 1980s and froth flotation is still not practiced widely to produce ultra-fine steam coal due to moisture problems.

The drying of coal is another beneficiation technique that aims at reducing the moisture content to ensure the impact on the heat availability in the boiler is minimised. The technique has been tried for over twenty years but has been largely unsuccessful to date due to costs and the historically low coal prices.

Such technology is important in that any system that allows the use of coal of a lower quality than that commonly mined is advantageous. Although their high inherent moisture content lowers their heating value and thus increases the cost of transportation and handling, their positive features, such as their low cost per Btu and excellent combustion characteristics, have, to date, been ignored. No commercial drying process is currently available that can economically produce a conventional, dried bulk coal product that will withstand the rigors of storage, handling, and transportation. Traditional thermal drying methods used to dry bituminous coal are not effective on sub-bituminous coal and lignite because of the resulting decrepitation of these coals.

More modern techniques include the use of coal in liquefaction and include those from the Energy & Environmental Research Center (EERC) in the USA to investigate alternative methods for converting low rank coals (LRC's) into economically viable liquid fuels. This led to the successful development of a direct LRC slurry liquefaction process at the EERC facility in Grand Forks, North Dakota, the world's largest research and development complex for investigating LRC's.

The EERC developed an integrated close-coupled multi-step process to take advantage of the higher coal reactivity and moisture content of LRC's to produce a product that may be easier to upgrade than products from liquefaction of higher-rank coals. The process utilizes hydrogen-donating solvents, the water–gas shift reaction, and lower-severity reaction conditions. Coal liquid yields of 80 wt% of moisture- and ash-free (maf) coal fed with conversion rates of greater than 93% have been achieved. A multi-step approach was taken to produce a tetrahydrofuran (THF)-soluble material that may be easier to upgrade in conventional catalytic hydrogenation. The process consists of three parts: 1) pre-conversion treatment to prepare the coal for solubilization, 2) solubilization of the coal in the solvent, and 3) polishing to complete solubilization of the remaining material. The product of these three steps can then be upgraded during a traditional hydrogenation step. Successful implementation of this process promises improved economic viability of low-rank coal liquefaction.

The hot-water-drying process is essentially pressure-cooking the coal in a water medium. It is known that water separates from LRC under conditions similar to those encountered during natural metamorphism, but metamorphism is achieved under extremely high pressure. It has now been found that, under suitable conditions of elevated temperature and pressure, lignite not only loses chemically bound water, but undergoes such a change that re-absorption of water does not occur when the coal is kept in a water phase at high pressure (a common problem with coal drying). This effect is a result of a change in the LRC itself, whereby the tars that form tend to seal the pore entrances. In simple terms, the process induces coalification in a condensed time scale of minutes rather than geological eras (millions of years), thus effecting a permanent reduction in inherent moisture. In other words, the LRC is changed from hydrophilic to hydrophobic, thus making it similar to some sub bituminous coals. Hot-water drying also offers an added advantage: the removal of sodium from the lignite during the drying process. Sodium removal is important since it reduces the risk of fouling and slagging in boilers.

3.1.2 Pulverised Fuel (PF)

PF boilers used coal crushed to a size of below 75μ, which causes the coal to be burnt within seconds of being blown into the boiler. Properly designed, the boilers can use a wide range of fuel from high quality thermal coal to lignite. Some 98% of the coal-fired boilers in the world are PF users but the average thermal efficiency is low – about 35% - partially reflecting the age of the fleet, which is over twenty years old on average.

The key to PF boilers is their versatility, using all types of coal and a wide range of biomass, including wood chips, olive pips and palm kernels. The future of pulverised fuel lies in the increasing development of supercritical and ultra supercritical boilers. These power plants operate at higher temperatures and pressures than traditional coal-fired plants, which results in higher efficiencies – up to 50% for ultra supercritical - and thus lower emissions, including CO_2. More than 400 supercritical plants are in operation worldwide and China is now installing supercritical plant as standard.

Supercritical is a thermodynamic expression describing the state of a substance where there is no clear distinction between the liquid and the gaseous phase. The cycle medium is a single-phase fluid with homogeneous properties and there is no need to separate steam from water. Once-through boilers are therefore used in supercritical cycles. Supercritical plants offer higher efficiencies than conventional, sub-critical plant. As Diagram 2 illustrates, modern high pressure and temperature boilers will create much higher thermal efficiencies.

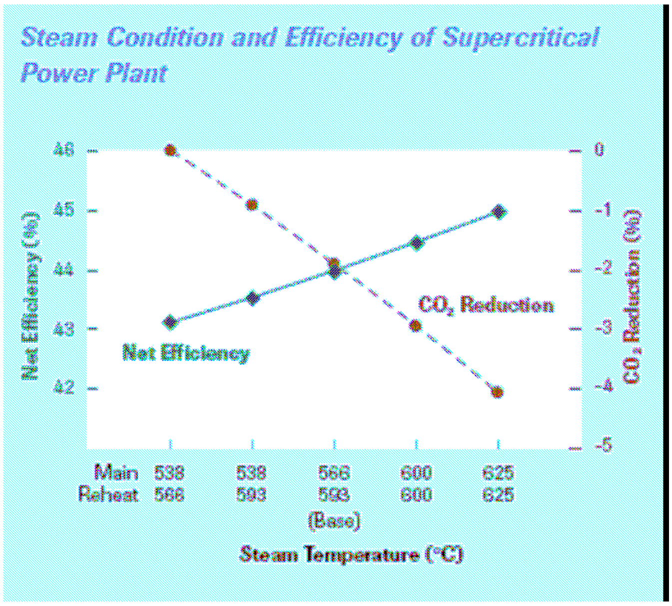


DIAGRAM 2 – Efficiency of high temperature and pressure boilers

Source: World Coal Institute

3.1.3 Fluidised Bed Combustion (FBC)

FBC can reduce SOx and NOx by 90% or more and are very flexible – almost any combustible material can be burnt. In the USA for example, FBC systems are increasingly used for abandoned coal waste, turning what could otherwise be an environmental problem into a useful source of power.

In fluidised bed combustion, coal is burned in a reactor comprised of a bed through which gas is fed to keep the fuel in a turbulent state. This improves combustion, heat transfer and recovery of waste products. The higher heat exchanger efficiencies and better mixing of FBC systems allows them to operate at lower temperatures than conventional (pulverised) coal-burning systems. By elevating pressures within a bed, a high-pressure gas stream can be used to drive a gas turbine, generating electricity.

Fluidised bed combustion technologies include:

- atmospheric pressure fluidised bed combustion in both bubbling (BFBC) and circulating (CFBC) beds
- pressurised fluidised bed combustion (PFBC)
- pressurised circulating fluidised bed combustion (PCFBC), which is being demonstrated.

Circulating Fluidised Bed Combustion (CFBC) is the version of the technology that has been most widely applied and for which there is the most extensive operating history. CFBC uses the same thermodynamic cycle as PCC and therefore its power generation efficiency is in the same range, which is normally between 38% and 40%.

Pressurised Fluidised Bed Combustion (PFBC) is based on the combustion of coal under pressure in a deep bubbling fluidised bed at 850°C. Depending on the velocity of the air through the fluidised bed, two PFBC variants exist – bubbling bed PFBC (lower velocities) and circulating bed PFBC (higher velocities). Pressurised pulverised combustion of coal (PPCC) is a technology currently under development, mainly in Germany. Similar to conventional pulverised coal combustion, in that it is based on the combustion of a finely ground cloud of coal particles, the heat released from combustion generates high pressure, high temperature steam, which is used in steam turbine-generators to produce electricity. The pressurised flue gases exit the boiler and are expanded through a gas turbine to generate further electricity and to drive the gas turbine's compressor; hence this is a form of combined cycle power generation

Acceptance for FB technology appears to be low. Poland leads the way in the implementation of the techniques at the Lagsiza installation. The primary advantage of FB is that it can use higher ash coals which are difficult to use in PF boilers due to high grinding costs. However, Lethabo power station in South Africa operates on a 50% ash coal feedstock so this is not a complete impediment.

The real potential in steam generation seems to lie with super critical and ultra-super critical boilers that are achieving around 45% efficiency, with the potential to reach 50%. These levels of improvement reduce CO_2 emissions by 25%.

'Ultra-supercritical' technology is expected to achieve efficiencies of up to 60% when it comes to market within the next decade, thereby halving emissions relative to existing standard plant. However, while the financial benefits from greater fuel efficiency easily offset the additional capital needed to buy such technology, the preference is still for least-cost sub-critical plant to meet accelerating demand, particularly in India where power sector reform has faltered and the government has numerous competing demands on spending.

So, the decision for power station design is not as cut and dried as using the best technology. India and China can only achieve their spectacular economic growth rates if cheap electricity is available. Economic considerations will predominate but environmental ones may be secondary, despite China's assertions of its commitment to reducing emissions.

Overall, it is likely that global average plant efficiency will rise and be driven mainly by the introduction of super critical and ultra super critical. It is possible that FB technology may be passed by. Stations will also be refit with improved systems but this will be rare as not many countries can afford to have plants off line for an extended period.

3.1.4 Integrated Gasification

In these systems coal is not burnt directly, but is reacted with oxygen and steam to form a 'syngas' composed mainly of hydrogen and carbon monoxide, which is cleaned and then burned in a gas turbine to generate electricity and to produce steam to drive a steam turbine, also for electricity. In these systems coal is not burnt directly, but is reacted with oxygen and steam to form a 'syngas' composed mainly of hydrogen and carbon monoxide, which is cleaned and then burned in a gas turbine to generate electricity and to produce steam to drive a steam turbine, also for electricity.

Large-scale demonstrations of IGCC are ongoing in the US (with the FutureGen Initiative), Europe, Canada and Australia, and demonstrations and pilot CO_2 storage projects are under way in Norway, Algeria, Canada and the US, although large-scale demonstrations of IGCC using CCS may be up to a decade away. Before this technology can be widely deployed, the costs of IGCC and CO_2 capture must clearly be reduced. The capital cost of IGCC is expected to become competitive from around 2015, and the cost of CO_2 capture using IGCC is expected to fall to \$10 per tonne of CO_2 over the same period – the targeted objective of the US Department of Energy. At these levels, IGCC using CCS may emerge as a viable CO_2 reduction measure if carbon prices in emissions trading markets are sustained at or above \$15–20 per tonne of CO2.

IGCC offers efficiencies up to 50%, with the prospect of 56% in the future – and so significantly improves the environmental performance of coal. IGCC technology may be the way towards an ultra-low emissions future, if combined with carbon capture and storage, and as part of a future hydrogen economy. Further development to improve reliability is ongoing.

The natural progression will lead towards Integrated Gas Combined Cycle. This combination can deliver power plant efficiencies in the region of 50%, with only a 3–4% energy penalty for the CO_2 capture and handling. Problematically, however, commercial deployment of IGCC is still largely unproven and costly.

3.1.5 Gasification and liquefaction

As discussed in this report, the attractiveness of coal gasification lies in the ability for the coal's energy to be released from seams that are un-mineable by conventional technology. This includes low quality seams at depth.

The issues of coal gasification from underground seams – ensuring no mining costs are involved – are discussed in section 3.5.

3.1.6 Carbon capture and storage

Carbon capture and storage technologies allow emissions of carbon dioxide to be 'captured' and 'stored' i.e. they are removed from the exhaust gases of the power station (either from conventional combustion or from gasification), and stored in such a way that they do not enter the atmosphere – thus reducing global warming.

Carbon storage is not yet cost-effective, even when combined with Enhanced Oil Recovery (EOR) and estimates from projects in Norway suggest costs of \$30 per tonne of CO_2, are applicable, but the required technologies are already proven and have been used commercially in other areas such as the food industry and chemicals industry. The key is to bring the different elements together at an acceptable cost, and research is ongoing to achieve this goal.

However, the advent of large scale CO2 capture is probably still some way off, at least in terms of having any significant impact on coal demand. This is because:

- The costs of the capture are high with a wide variety of estimates. The IPCC estimates the costs of carbon capture and storage to be approximately US\$40–60 per metric ton of CO2 (IPCC 2006), while the International Energy Agency estimates that capturing and storing CO2 would cost from \$50 to \$100 per ton (Carbon Market News December 15,2004). Several other studies estimate the total costs to range from about \$20 per ton of CO2 up to about \$100, depending on the capture source, modes of transportation and types of reservoirs (Torvanger, Kalbekken and Rypdal 2004). Compared to current prices in the European emissions trading market of about 8.5 Euro, or about US\$11, it is fair to conclude that the cost obstacle is at present significant, but there is probably scope for reduction of costs in the future through technical developments and wider application (IPCC 2006).

- Of the total costs, the capture costs are expected to constitute a much larger share than transport and storage, about 70–80 per cent according to some sources. Reducing capture costs is hence identified as the major economic challenge. But as noted above, this is only relevant with regard to CO2 from large emission sources like power generation and not CO2 separated from the gas stream

- Therefore, the concept of CO2 capture has a doubtful impact due to cost and the fact there is considerable doubt that there will be sufficient storage reservoirs as deep ocean storage has been largely discounted. It is highly likely that carbon prices will rise significantly, but this will take some time, with prices rising in the next decade to a level still below that which would prompt power generators/other emitters to significant shifts towards CCS.

It is probable that CCS on a commercial scale is some way off and may be limited to certain regional areas where old oilfields have the capacity to store the gas effectively. Even this may prove difficult. In the North Sea, for example, none of the existing oil and gas delivery pipelines can be used for CO2 transport and these will have to be constructed, or possibly existing pipelines re-lined.

Even though efficiency losses from CCS may be minimal due to a lack of technology deployment, it is likely that the overall efficiency of the global power plants will rise only slowly. A newly built standard pulverised coal plant achieves a typical efficiency of around 36%. But 'supercritical' technology, employing new materials, can accommodate higher steam pressures and temperatures, achieving around 45% efficiency, with the potential to reach 50%. These levels of improvement reduce CO_2 emissions by 25%.

For coal use, the predictions suggest coal use will rise in real terms and will probably amount to 20% of the energy mix but expectations vary widely – from 10% to 30%. Overall, we feel that power station efficiency will rise about 1% per five years (although the development may not be linear), which suggest by 2030 the average efficiency will have improved from about 32%-34% to close to 40%.

Given that overall coal production is likely to double in that period the impact of improved efficiency of power plants is unlikely to diminish coal requirements by 5%. This is based on the assumption that by then the power generation fleet with have no more than 50% high efficiency stations. This means that the impact on coal demand could be +/- 400 million tonnes but we must acknowledge the wide variation in predictions on GDP, population growth and rival fuel availability, as well as efficiency improvements in electricity generation across the spectrum.

4 SPECIFIC AREAS OF TECHNOLOGY

4.1 Better mapping techniques

Although a dramatic statement, it is unlikely that significant unknown coal deposits are likely to be located in the world. The geological techniques that are available to the geologist are largely oil-field techniques. It should be recalled that until the increased coal prices of the last three years, the financial return from coal mining rarely exceeded 10% per year and left little capacity to develop expensive and revolutionary exploration techniques. These techniques, discussed below, have the potential to better define coal resources but, as yet, have little potential to improve the definition of cleaner coals other than conventional analysis.

The techniques are largely geared towards the better definition of resources that will allow economic assessments of the mineability of the deposit. The main techniques are summarised below.

4.1.1 Aerial magnetic surveys

These surveys have improved primarily due to the application of sophisticated electro-magnetic aerial equipment in coal mines. In southern African mines the coal seams are heavily intruded by Jurassic dolerites dykes and sills. These either burn the coal or cut through it and due to their hardness and possible seam displacements, which makes mine planning difficult. The presence of these intrusives is the main reason why so few long wall or short wall mining methods are used in South Africa.

The key advances have been the use of helicopters in the survey. This allows the magnetometer to be flown slower and closer to the ground (about 30 metres), whilst hugging the terrain, better than fixed wing aircraft.

With helicopters controlled by GPS systems, flight lines can be flown much closer than previously possible. The system primarily works where the dykes are magnetic and locates dykes that are sub-vertical and very difficult to identify by traditional (vertical) surface drilling. The aerial survey is much cheaper and more effective than seismic work.

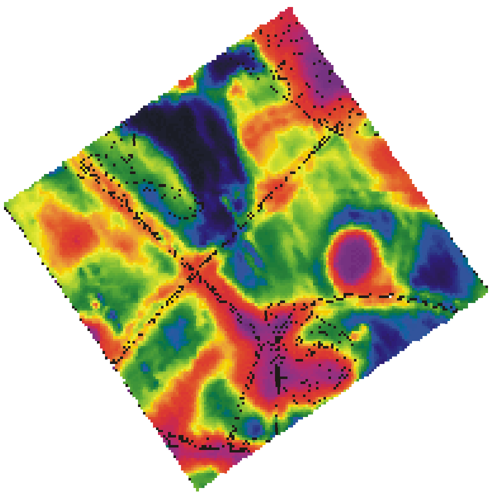


DIAGRAM 3 – Aerial magnetic survey of Forzando mine, South Africa

Source: RWE

The coal seam is cut by diabase (dolerite) dykes, and a sill lies at a varying distance under the coal. Not all of the dykes appear on the magnetic data. The heat of the intrusions devolatilises the coal, reducing its economic value, and the hard dikes are a hazard to the coal mining equipment. Drawn on the geophysics map are the locations of the previously known dykes and *the areas of de-volatilised coal (grey). The map shows a parallel pair of resistivity anomalies straddling each dyke, the dual anomaly representing the dual peak normal for coplanar coil pairs over a narrow vertical conductor. The coaxial resistivity responses show single peaks over each dyke, but are more sensitive to flight direction/strike coupling. The dual track anomaly of the coplanar data tends to be more obvious. Both data sets are collected on a normal DIGHEM survey. Several previously unknown dykes are apparent by their dual parallel anomalies, some of which have since been defined by drilling. Many areas have much more subtle anomalies due to thin dykes or non-magnetic, cooler felsic dykes. Extensive data enhancement and careful interpretation are necessary to detect and map the dykes.*

The broad, non-linear resistivity highs match those locations where the underlying sill comes in close proximity to the coal (< 20m), and devolatilises the coal. Again there is good correlation to the information gained from drill holes. A DIGHEM survey in advance of the drilling could help design the drilling pattern, after which the drill results and the HEM data could be combined into an accurate map of the problem areas.

The technique is a way to define the mineability of deposits, it does not define them. In other words, it is a technique that locates some structural complexities that define how easy or difficult mining will be and which methods are best used.

4.1.2 Drilling technology

Drilling remains the standard exploration process in coal mapping and exploration. Allied to this, wire line logging has improved to levels that can reduce exploration costs. Wireline logging involves the analysis of boreholes by electronic means. Probes are lowered into boreholes that can help define the raw quality of the coal and reveal important data about the rock types around the seam that can yield useful rock mechanic data – such as joint spacing, rock strength and so on – that can help mine design.

Wireline logging can reduce expensive coring by drilling, so that every sixth to eight hole can be open-holed, which is much quicker and cheaper, being about one-third of the cost of cored boreholes.

Wireline logging helps the understanding of the geology but still lacks the definition (in coal, anyway) that can allow drilling to be significantly reduced. Drilling is usually undertaken by coring, which is relatively slow and expensive, but recovers accurate samples for analysis. Where possible, open holing is faster and cheaper but sampling is less accurate. Again, the technology helps reserve definition but does not locate new deposits. Although progress has been made, wireline logging does not provide data on the washability characteristics of the coal seams. Although some costs can be saved by coring and physically analysing a certin number of boreholes (usually one in four pr one in six), the technique remains excellent at identifying core loss, seam thickness and basic coal qualities.

The area where drilling and exploration has developed is in the field of directional drilling. Initially, coal exploration techniques where less interested in directional drilling as it has less application. However, latest developments include Tight Radius Drilling (TRD) which allows boreholes drilled from surface to the seam and then travel along the seam. Such techniques are invaluable in locating faults and intrusions that are often vertical and sub-vertical in nature that means traditional drilling will not locate them, although they may have a devastating impact on long wall operations.

In seam drilling in coal mines has similarly advanced with better steering techniques and longer distances achievable, but this is an exploration technique that is usually used in conjunction with methane drainage and is undertaken from existing mines. In seam drilling can be used to test areas of flooding and gas accumulation where old workings are known to exist. The limitation is that drilling can only usually be carried out 1-2 kilometres ahead of the workings

4.1.3 Seismic technology

One of the attractions of opencast mining is the flexibility that the technique has compared to the relatively rigid and inflexible longwall operations.

Planning longwall operations is complex and highly expensive business. Committing to such a project is dependent on extensive exploration that is high cost owing to the typical depth that longwall mines operate at - below 200m. Longwalls are not equipped to handle seam discontinuities but locating them can be problematic. Seismic technology works either from borehole to borehole, from surface to borehole or from in seam locations in underground operation.

The concepts of seismic exploration in coal are still based in the oilfields technology. The advances relate primarily to the computing and interpretation power. For exploration in underground settings, such technology would rarely be used in mines planning bord and pillar extraction because of the flexibility of the system to deal with changes in seam height and minor faulting and dipping compared to longwall mines.

Multi-component seismology has received considerable attention in the petroleum sector. Remarkable advances have been made in multi-component acquisition and processing in recent years and there are a number of examples where converted-wave seismic techniques have proven more successful than conventional seismic imaging methods. In contrast, there has been little effort devoted to shallow, high-resolution converted-wave imaging in the coal sector. This is despite the knowledge that coal seams generate particularly strong converted waves.

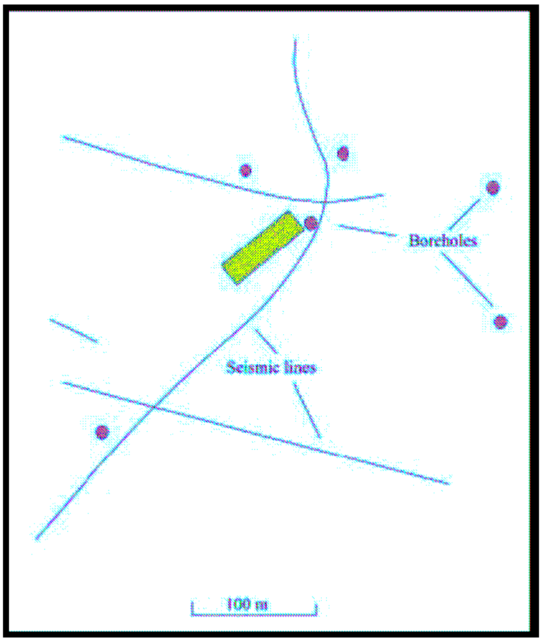


DIAGRAM 4 – Seismic and borehole layout for a typical exploration site

Source: DTI UK

2D seismic, at its best, has a resolution of ~5 metres at the depths under consideration, and several lines are required to eliminate errors and improve the correlations for topography and faulting. New lines, strategically placed along the target trajectory could improve accuracy especially if these can be calibrated against the data from nearby exploratory boreholes. A typical layout taken from an actual target site is shown in Diagram 3.

3D seismic survey technology is now available for the structural exploration of coal, in which multiple linear arrays of geophones are located over the area and the source lines are shot at right angles. This geometry produces a continuous geophysical image, with the following advantages:

- Improved resolution by a factor of three. At the target depths, faults as small as 2m can be mapped in good seismic data areas.
- Miscorrelation of faults is almost eliminated.
- Faults can be located correctly irrespective of variations in seam dip.

These advantages have to be offset against the cost of 3D seismic surveys and the fact that a minimum area of around 1-2km^2 has to be surveyed.

Another innovation in seismic surveying, which might be useful for the assessment of seam continuity and the detection of small faults is borehole-to-borehole seismic (BBS). A channel seismic wave, created by detonation in a well at coal seam depth, is
detected in neighbouring boreholes by geophones. The original BBS method requires the geophones to be cemented in an uncased hole (a costly procedure) but significant developments now allow geophones to be attached to the casing to make the method more acceptable. Detonation in wells will cause degradation, however, which could limit the further use of the source well.

In designing the trajectory, the basic configuration common to the construction of all inseam wells from the surface has three parts:

- A vertical section from surface to coal seam depth.
- The curved or build-up section to transfer direction to that of the seam.
- A long-reach inseam section with branching, to access the seam for the purposes of tracking the seam)

4.1.4 General mapping techniques

The most significant advance in mapping has been the development of GPS technology. Exploration in remote areas is now much easier as the identification of seams by immediate and accurate positioning, including elevation. The need for slow and often difficult manual surveying in challenging terrain has been eliminated. The modern systems are not only accurate and reliable but provide results much faster than was previously possible.

The ability to capture geological information directly into databases greatly aids mine design systems that maximises coal extraction by assessing a variety of options based on the geological data available. There are many modern systems that use the electronic geological databases such as Surfer or Runge.

4.2 Increased recovery from underground mines

4.2.1 Mine productivity

Key elements in future global demand are productivity gains in mining and improved efficiency in combustion. Productivity per man and year rose between 5 and 10 % in the 1980s and by between 10 and 15 % in the 1990s. This growth was not only due to increased labour productivity, but also to the closing of uneconomic or small (and often illegal) mines, the liberalisation and restructuring of coal industries, the transfer of know-how and technology to newcomers and the expansion of opencast mining versus underground mining. Productivity growth is expected to continue but at a slower rate than previously. This is because some of the long-established supply countries are finding even maintaining productivities difficult and, as reserves dwindle, more difficult coal to mine is being accessed.

The interesting point is that mines that operate in different countries produce coal at similar costs, no matter what the productivity is. Australia is finding production costs rising due to higher energy cost (because of the oil price) and high labour costs. The near term projects in thermal coal that are due to come on stream in the next two to three years in Australia all exhibit significantly higher costs than existing operations, with the lower cost new mines having total FOB costs of over $30 per tonne.

South Africa, with productivities that are around one-third those of Australia, still produce export coal at very similar costs. South Africa averages FOB costs of about $23 per tonne (ranging from $19-$30 per tonne) whilst Australia averages $26 per tonne (range $19-$40). These issues are important for any CCT plants that operate in Europe and much of Asia where indigenous coal supply is not available.

The diagram overleaf indicates our estimation of typical productivities:

Average country productivities

Country	Productivity tonnes per man per year
Australia	22,500
USA	20,000
Canada	16,000
China	Estimate 10,000 on large export mines
South Africa	8,000
Colombia	5,500
Venezuela	4,400
Indonesia	3,500
UK	2,500
Poland	800-1000
Germany	<1,000

DIAGRAM 5 – Average coal mining productivities

Source: Energy Edge

South Africa has improved its coal mine productivities significantly over the years but this has come at the cost of much higher wages, which effectively means production costs have increased in line with declining employment.

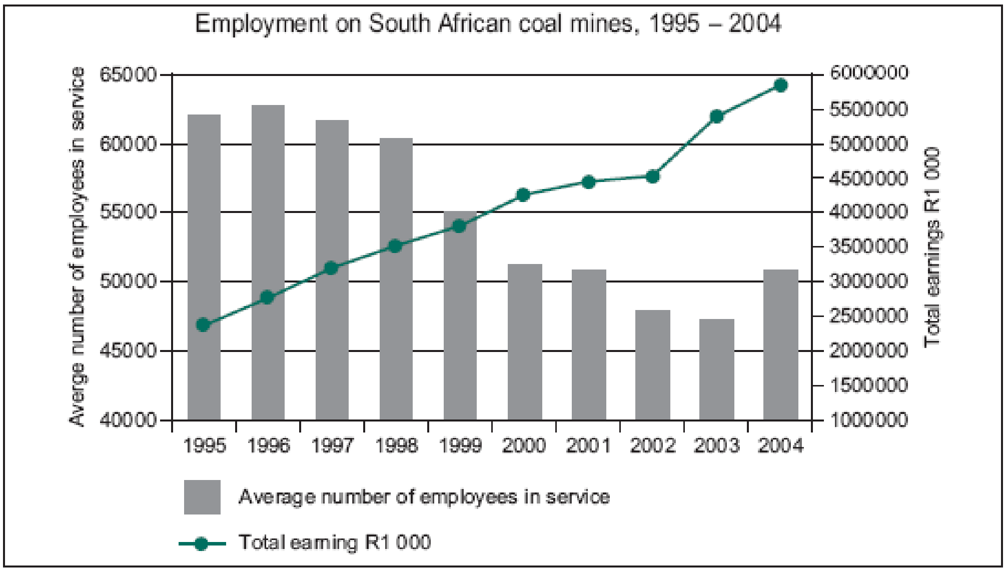


DIAGRAM 6 – Employment in South African mines

Source: Chamber of Mines

This is not to suggest that productivity is not important, it is one method of reducing costs and ensure profitability, but not the only one. It appears that countries like South Africa, Indonesia, Colombia and eventually India, that have large and relatively poorly paid labour forces can achieve productivities of between 6,000 tonnes per man per year (tppy) and 8,000 tppy. Although India, currently with productivities of less than 1 tppy (underground) and 15 tppy (opencast), will improve its productivities, it will be unlikely to eventually exceed levels seen in other producers in South America or Africa.

4.2.2 Mining methods

There are four primary methods for mining coal:

- Opencast by dragline (or bucket wheel excavator)
- Opencast by truck and shovel
- Underground bord and pillar
- Underground longwall

Overall, opencast coal mining has improved faster and extraction rates maximised. This is due to:

- Increased availability of machines. Draglines, the primary method of moving overburden and increased in size so that most use buckets of over $50m^3$ and boo lengths of almost 100m. There are examples of much larger buckets but these are the standards. Other equipment has also grown and haulers now carry over 300 tonnes (although smaller, more flexible 100 tonne haulers are widely used) and shovels can move up to 100 tonnes, although, again, smaller units are often preferred
- Truck and shovel operations, both removing overburden and mining coal are used where the geology is more complex than is the case with the flat-lying seams that draglines can exploit. By definition, such operations are more complex and tend to have lower productivities.

Recent improvements in opencast mining include the introduction of far better monitoring systems for machines, allowing operators to understand the machine's performance, utilisation and reason for delays and stoppages.

- Longwall productivity has improved with the advent of longer faces of up to 400m and larger shearers that move faster and with improved cutting depths. This is allied to wider and faster belts, up to and exceeding 60 inches. The only real risk with the method, which is highly productive, is the incidence of faults and discontinuities which disrupt the operation.
- Bord and pillar mining is usually undertaken in relatively shallow deposits unless the pillars are later extracted. The mines use continuous miners and the coal is moved either by shuttle cars or a continuous haulage system. Again, bigger machines mean that coal faces of up to 5m or more can be cut in one pass and productivity has improved as machine size and belt capacity has increased.

The concept that opencast mines are more productive is generally correct, with a factor of 20%-30% being common, in Diagram 7, of leading low cost coal exporters, it can be seen there is a dominance of opencast operations.

Future long term reserves show that underground mining will continue to be at least as common as opencast. A brief summary of the long term resources of major producing countries is as follows:

- In South Africa, much of the future production will come from underground mines with some opencast in the northern coal block of the Waterberg. However, its distance from the port and possible new power plant sites that makes mining here more expensive.
- Indonesian production is almost all by opencast (truck and shovel) methods and this will not change significantly in the near term. This is due to the faulting and steep seam dips and soft roof and floor material.
- In Russia, coal will be mined by both opencast and underground methods in fairly equal balances but much of the opencast coal will be lignitic in nature.
- The US has seen a considerable move to the thick, low quality coals of the west, notably the Powder River Basin. These deposits have much higher productivities owing the thick nature of the seams. The older mines of the east, notably the Central Appalachian Basin have seen productivity declines from the mainly underground operations. However, the move to the western coals – much of which is railed east – was caused by the Clean Air Act. After 2018, all power plants in US will have sulphur scrubbers and other environmental equipment fitted which will prompt moves back to Northern Appalachian and Illinois Basin coals that are currently difficult to burn whilst adhering to emission limits.

Mine	Country	Exports Mt	Total FOB
Blair Athol O/C	Australia	11.4	**18.4**
South Witbank U/G	South Africa	2.1	**18.6**
Sebuku O/C	Indonesia	2.6	**19.2**
Mandiri Intiperkasa O/C	Indonesia	0.6	**19.8**
Twistdraai U/G	South Africa	7.6	**20.4**
Bengalla O/C	Australia	4.7	**20.6**
Berau O/C	Indonesia	6.9	**20.6**
Kangjiatan U/G	China	5.5	**20.7**
Yujialiang U/G	China	6.1	**20.7**
Greenside U/G	South Africa	2.5	**20.8**
Shangwan U/G	China	2.8	**21.0**
Jembayan (Separi) O/C	Indonesia	1	**21.0**
Middelburg O/C	South Africa	6.6	**21.0**
Drayton O/C	Australia	2.9	**21.2**
Dahaize U/G	China	0.9	**21.2**
Witcons U/G	South Africa	1.2	**21.4**
Daliuta-Huojitu U/G	China	8.3	**21.4**
Beltana No.1 U/G	Australia	2.9	**21.4**
Douglas O/C	South Africa	3.6	**21.5**
Loa Janan O/C	Indonesia	3.2	**21.5**
Kaltim Prima O/C	Indonesia	22.2	**21.6**
New Clydesdale U/G	South Africa	0.8	**21.6**
Phoenix U/G	South Africa	0.9	**22.0**
Kideco Jaya Agung O/C	Indonesia	12	**22.1**
Wulanmulun U/G	China	1.4	**22.2**
Koornfontein U/G	South Africa	4.8	**22.4**
New Clydesdale O/C	South Africa	0.8	**22.4**
Jorong Barutama Greston O/C	Indonesia	2.1	**22.5**
Optimum O/C	South Africa	6.3	**22.5**
La Loma O/C	Colombia	22.1	**22.8**

DIAGRAM 7 – Leading export mine costs

Source: AME

- Australia will see over 120 million tonnes of new production, both thermal and coking coal coming on line by 2010. Of this, over 40 Mtpa is due by 2008 and about 70% will be opencast. The trend will continue but it is likely that more mines will be a combination of opencast and underground, using underground methods accessed from the highwall, when strip ratios increase to a level that makes continued opencast mining uneconomic.
- Colombia and Venezuela will continue to increase expansion but this will be primarily by opencast methods
- China has extensive coal resources but they are increasingly deep. It is believed that little open-castable resource remains and most reserves are very deep. This suggests that China will lead such technologies as underground gasification that allows the energy to be captured without mining being needed.

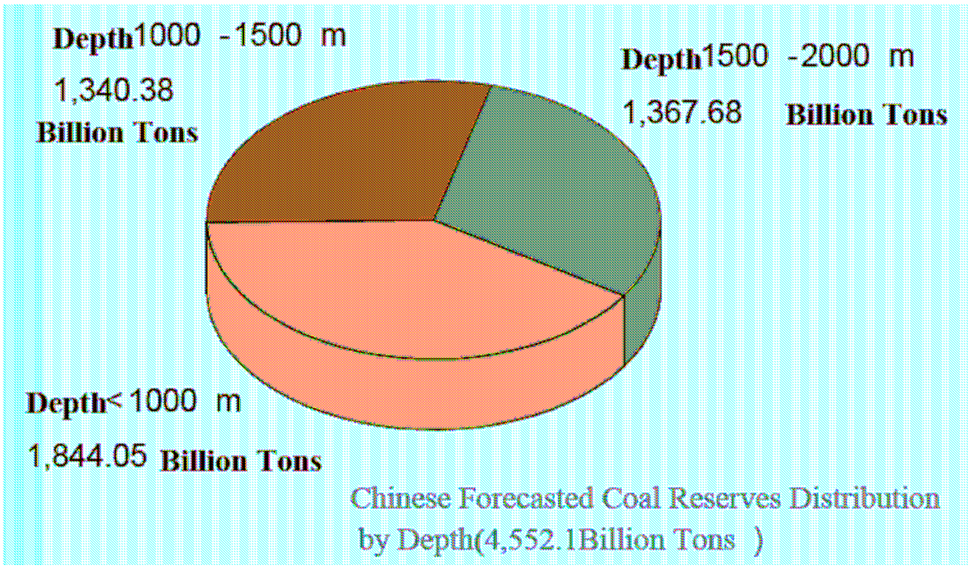


DIAGRAM 8 – Chinese coal resources by depths

Source: Pan, Fudan University

Currently, about 40% of the world's coal is produced by opencast methods and this will move towards parity in the future. This will be because increased production from Colombia and Venezuela, Bangladesh, Pakistan and Vietnam will partially replace deep mined coal from Europe and, after 2015, from South Africa.

4.2.2.1 Mine extraction factors

In terms of extraction rates, opencast operations are considered to be operating at a rate that is realistically as high as possible. Mines are carefully designed to minimise any losses during extraction. Most opencast mines are less than 100m deep but they can be deeper in a multiple seam environment.

Better and larger equipment (and therefore lower costs), with higher coal prices will allow more seams to be mined by opencast methods where strip ratios are high (usually over 10:1, but this is variable). The equipment benefits will do little to extract more coal nor improve extraction factors as these are already about 85%. Coal that is left is usually too thin to be extracted economically and it is difficult to imagine the criteria currently applied changing significantly.

More opportunities lie in the underground sector. Bord and pillar operations, by definition, usually leave pillars behind to act as a primary means of support for the overlying strata. Whilst suitable for shallow deposits, the extraction factor declines with increasing depth and seam thickness. For many South African deposits, underground operations are typically 30-60m deep with seam thickness of 3-6m. This means extraction factors are usually between 50% and 70%. At depths towards 100m, the relatively thick seams mean that extraction factors drop below 50%, which is usually uneconomic. Bord and pillar operations can be laid out to extract pillars after mining and allowing the roof to collapse (a technique known as stooping).

In countries like South Africa, the thick seams mean the surface disturbance under total extraction would be too significant. The surface land use would be badly affected, especially as the crops growth rely on perched water tables that will be destroyed during the ground caving. Therefore, few South African mines were laid out for stooping, where pillars are left larger than necessary to aid productivity during the removal process.

However, more operations are looking at pillar extraction by opencast methods. This may allow the exploitation of an estimated two billion tonnes of relatively high quality coal but it usually requires a power station to take the low quality coal and sophisticated washing plant to be economic.

Bord and pillar mining is more flexible than longwall mining and is better equipped to deal with discontinuities. However, the move from drill and blast techniques to continuous miners has meant the exploitation of thicker seams (over 6m) is more problematic. This is because roof bolting (a secondary roof support system) is difficult at such heights.

The exploitation of thicker seams in underground operations is still problematic, especially in longwall mines. Four generic methods have been identified as having thick seam potential. These are: extended height single pass longwall (SPL); multi-slice longwall (MSL); caving longwall systems (CL), including longwall top coal caving (LTCC); and hydraulic mining (HM).

Longwall mining is a method that allows a considerable amount of the coal in a reserve to be extracted – typically, well over 80% is extracted. The coal is mined by a shearer operating under protective shields. In search of higher productivities, face lengths have increased and now are up to 400m.

Most longwalls operate in seam thicknesses up to 5m and at depths down to 1000m below surface. The typical configuration is a double-ended ranging shearer (DERDS) that has two cutting wheels that ensure the full seam is removed in a single pass.

Above 5m thick, it is more problematic to remove all the coal as the face can become unstable at such seam thicknesses. For such seams, there are options to use a multi-slice technique where the process effectively repeats the single pass system. The diagrams below represent the options which are either to backfill the mined area with sand to allow the machinery to operate on the sand:

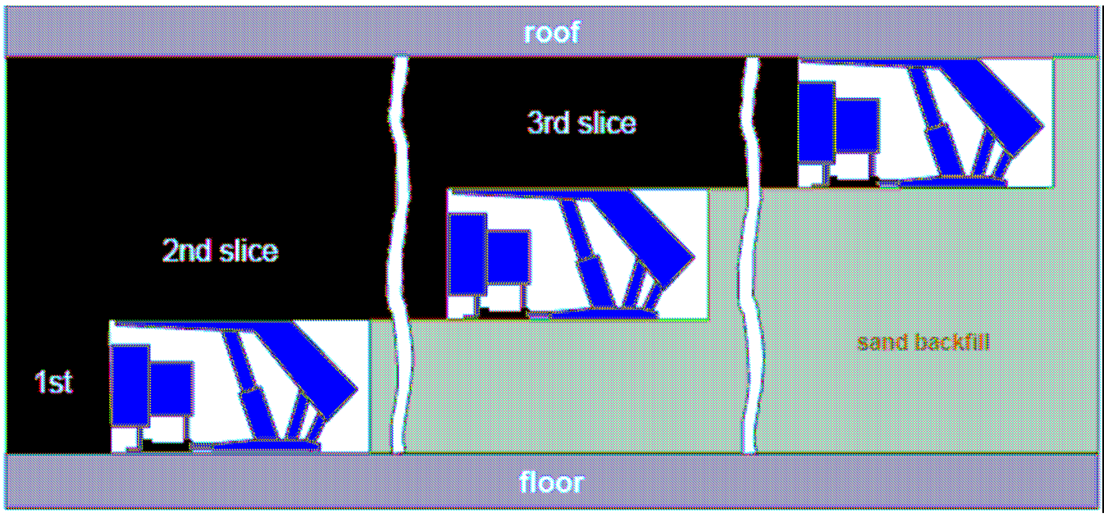


DIAGRAM 9 – Multi-slice Longwall with Sand Backfill

Source: Energy Edge

This method may allow a single longwall to operate cyclically, but there are options (although rare) that allow several machines to move in sequence, with either a coal roof or an artificial roof:

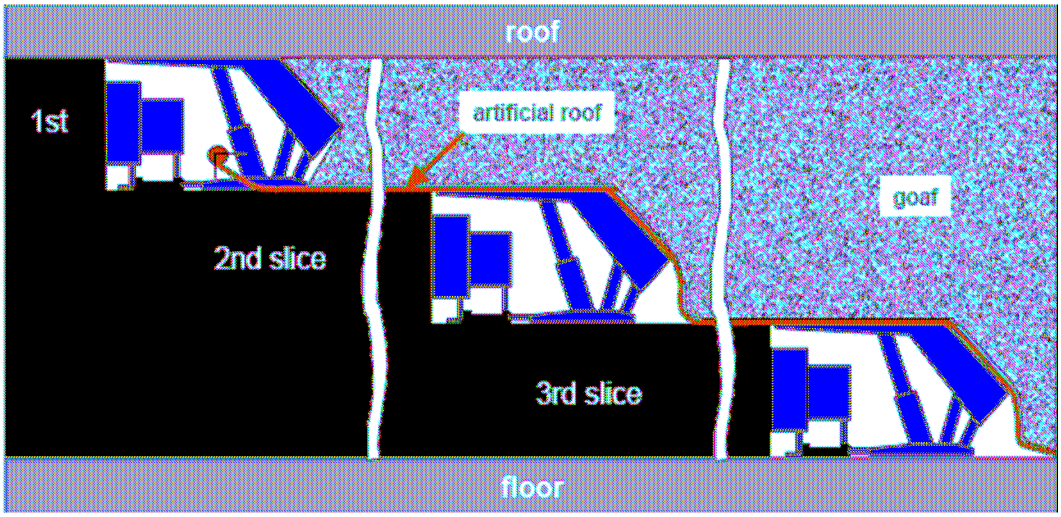
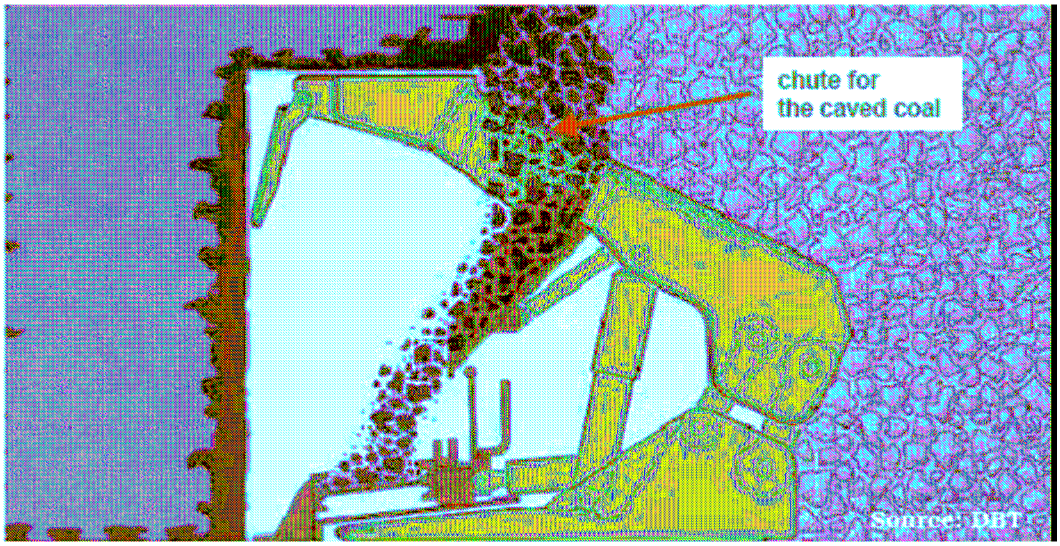
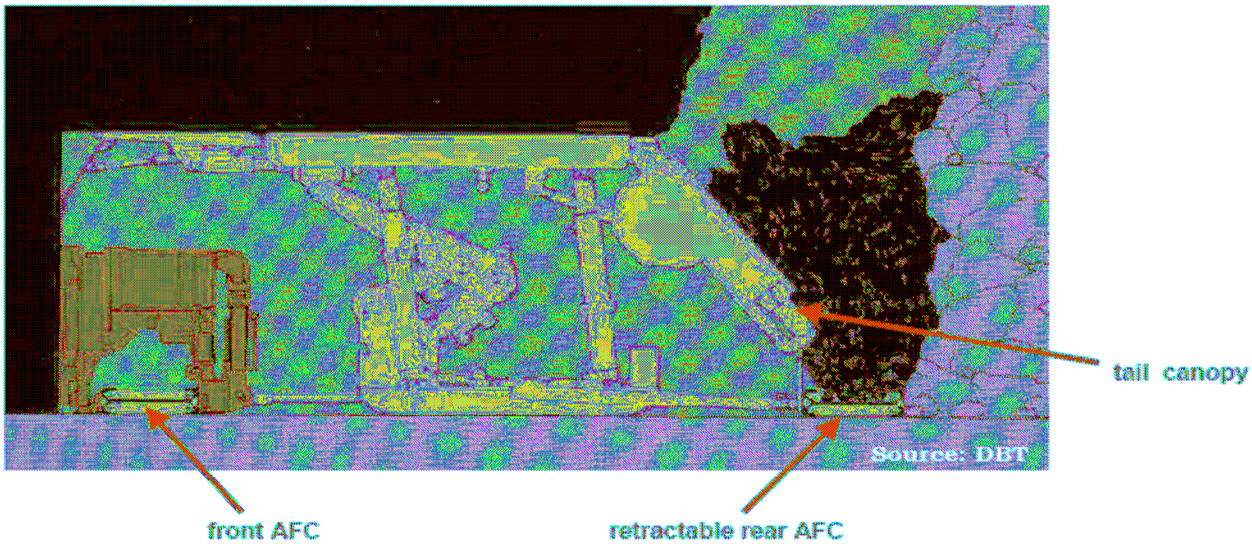


DIAGRAM 10 – Roofed Multi-slice Longwall

Source: Energy Edge

Finally, some systems use a top coal caving system, often used in thicker coal seams in China. Here, the initial operation uses a conventional system and allows the top coal that cannot be cut to collapse and be captured by belt conveyance systems:





DIAGRAMS 11 – Longwall Top Coal Caving

Source: DBT

The Chinese industry had reported average production rates of 15,000 to 20,000 tpd from an LTCC face; up to 75% recovery of 8m+ thick seams using a 3m operating height longwall; and +5 MTPA face production. There are now well over 70 LTCC faces in China. A new semi-automated 300m long LTCC face was installed at the Xinglongzhuang Colliery of the Yankuang Group, in Shandong Province, in August, 2001, with production capacities of at least 7MTPA.

The major perceived benefits of the LTCC method include:

- Operating Cost Reductions: The LTCC method enables potentially double (or greater) the longwall recoverable tonnes, per metre of gateroad development, thereby reducing the development cost/tonne significantly, and reducing the potential for development rate shortfalls leading to longwall production disruption.
- The LTCC method offers a viable means of extracting up to 75% to 80% of seams in the 5m – 9m thickness range. Single pass longwall is considered to be limited to an upper height of 6m, and is currently only operating at or below 5m.

Hydraulic Mining (HM) is simply the practice of using dynamic water pressure to break coal from the seams.

There is, therefore, every reason to suppose that the extraction of thick underground seams can improve. Although longwall mining has a certain inflexibility with varying seam widths, the basic extraction factor is much higher than bord and pillar operations and thick seam improvements and the use of continuous miners in remnant coal areas where longwalls cannot work will see overall extraction factors increase.

4.3 Utilisation of coal mine methane (CMM)

4.3.1 Potential for Coal Mine Methane Extraction and Utilisation

For the coal industry, methane is a nuisance and a safety hazard. As mining technologies advanced to allow for extraction of coal from deeper seams, it became more and more essential for mine safety to come up with technologies to remove this gas. At first mines used ventilation systems to dilute and remove methane, but with gassier conditions boreholes were drilled to remove the methane at medium and high concentrations. Starting more than 50 years ago a few coal mines used some of this gas for local heating purposes. With mines increasing in depth, by the 1960's and 70's technologies developed to more effectively drain gas which was necessary in order to allow for some of the deeper, gassier coal seams to be mined. The more recent recognition that methane is a greenhouse gas is now stimulating further policy and commercial interest harnessing this gas as a low-cost emission reduction option.

What impact might coal mine methane have on clean coal energy supply? And more importantly for this relatively small energy resource, what impact may it have on abating carbon emissions? This section of the report attempts to provide a general overview of the issues and opportunities in coal mine methane.

4.3.2 Description of resource

Coal mine methane (CMM) is a subset of coalbed methane (CBM). CBM is formed during coalification, the process that transforms plant material into coal. Most CBM is found in coals that probably will never be exploited, but CBM is now a major unconventional source of natural gas.

Coal mine methane is the coalbed methane released due to mining. If not used, this methane, which is a potent greenhouse gas, is typically vented to the atmosphere. CMM resources at the macro-scale should be viewed as the projected emissions from mining, as CMM is dependent on mining, and thus the maximum amount of available gas is the amount liberated during mining. Reserves of CMM can be calculated by taking the average emissions per tonne of coal mined and multiplying it by coal reserves.

There is no comprehensive and consistent database of CMM reserves and they are difficult to estimate, but current attention to methane emissions from coal mining gives an indication of the potential, with the greatest potential found in the centres of underground coal mining: China, the U.S., and the Former Soviet Union. Using emissions projections for 2010 prepared by the U.S. Environmental Protection Agency (US EPA) one can assume that between 25 and 60% of total emissions of 28.6 billion cubic meters (BCM) may be produced from gas drainage wells, giving a global projected consumable gas production level for 2010 of between 7 and 17 BCM.

While there are a number of CMM projects that are significant energy projects, the energy resource is two orders of magnitude smaller than coal and natural gas. Multiplying the 60% potential gas production level of 17 BCM by the coal reserve/production ratio gives coal mine methane a maximum potential "reserve" of 2,635 BCM – significant but not sufficient to transform global energy supply and demand.

Attention to this resource is paid because of the emission reduction potential. This is significant with year 2010 emissions estimated at over 400 million tonnes of CO_2 equivalent. The deployment of technologies to use the remaining emitted methane is rapidly developing and will be discussed later.

Unit	Hard Coal Reserves	Natural Gas Reserves	Coal Mine Methane "reserves"
Standard measure	478 (billion tonnes)	180,000 (billion cubic meters)	2,635 (billion cubic meters)
Billion tonnes oil equivalent	319	162	2.4
Proportion	66%	33.5%	0.5%

DIAGRAM 12 – CMM reserves compared to coal and gas

Source: Calculated from BP Statistical Review, 2006

Emissions of CMM in the EU-27 are relatively small, with in 2005 an estimated 40.8 million tonnes of CO_2 equivalent principally from Poland, Germany, the UK, and the Czech Republic. The greatest emitters are China (136 million tonnes CO2e), the United States (55), and the Former Soviet Union (59).

Country	**2005**	**2010**	**2015**	**2020**
China	135.7	153.8	171.8	189.9
United States	55.3	51.1	46.4	46.4
India	19.5	23.1	28.4	33.6
Australia	21.8	26.4	28.2	29 7
Russian Federation	26.3	27.5	26.9	26.3
Ukraine	26.3	24.6	23.6	23.2
North Korea	25.6	24.3	23.1	21.9
Poland	11.3	10.6	10.3	9.8
South Africa	7.4	7.2	7.1	7.4
United Kingdom	6.7	6.6	6.4	6.2
Germany	8.4	7.7	7.1	7.4
Kazakhstan	6.7	6.4	6.1	5.8
Columbia	3.4	4	4.7	5.5
Mexico	2.5	2.8	3.3	3.7
Czech Republic	4.8	3.9	3.1	3
Rest of the world	**26.5**	**27.5**	**26.6**	**31.1**
World Total	**381.1**	**407.6**	**425.6**	**449.5**

DIAGRAM 13 – CMM emissions and projections for selected countries ($MMtCO_2e$)

Source: US EPA, 2006

4.3.3 Extraction technologies

When mine ventilation systems cannot safely remove the methane released during mining, coal operators drill into the coal seam or adjacent volumes to drain a gas with higher concentrations of methane.

Advances in directional drilling are the most important for CMM applications. Directional drilling for mine degasification developed during the 1980's, with the application of steer-able motors and precision borehole survey systems to drain gas from within a mine's coal panels developed for mining. These horizontal boreholes can extend in excess of 5000 feet (1500 meters). The results of horizontal drilling are lower *in situ* gas contents and the produced gas can be at or near pipeline quality, making its sale or direct use attractive.
Drilling and completion technologies adapted from the oil and gas industry, most commonly the drilling of vertical wells from the surface and hydraulic fracturing of the coal seams has been used, especially in the U.S., to remove a significant proportion of methane from coal seams in advance of mining.

Surface directional drilling into coal seams is a newer application for CMM. This technique can from a single site produce gas over a large area. Compared to in-mine directional drilling, this technique eliminates the need for in-mine access to the coal and facilities that interfere with mining, and no piping of the gas to the surface is required. The coals can also be drained for a longer period of time into coals further in advance of mining, which results in higher production levels. CDX Gas first developed a surface directional drilling program at the Pinnacle Mine in West Virginia, with reports of 80-90% of all gas recovered in a two-three year period. These technologies have also been applied by Mitchell Drilling drain CMM in Australia.

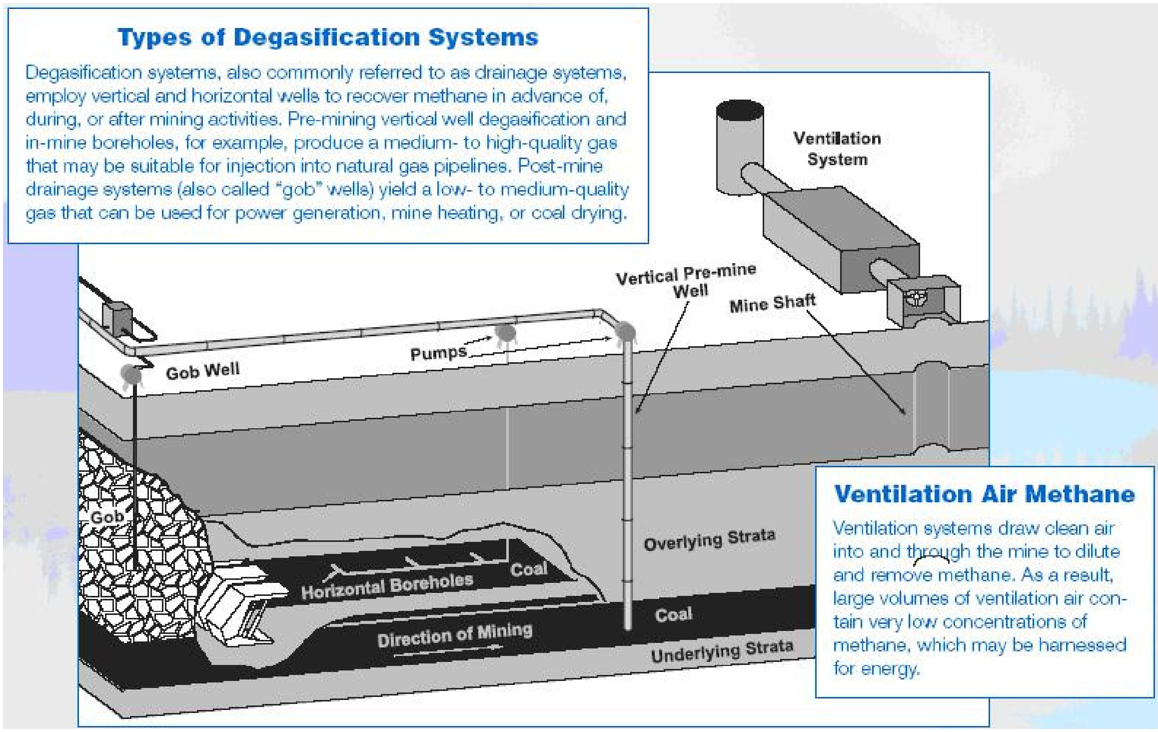


DIAGRAM 14 – Means of removing methane from coal mines

Source: US EPA, 2005

Most of these innovations in CMM production have taken place in the U.S. or Australia, and to date there has been relatively little commercial activity applying these technologies to other countries. Often attempts are thwarted by the low permeability of many coals compared to those experienced in the U.S. and Australia. The exception is China, where the use of vertical frac wells, and in-mine and surface directional drilling techniques to drain gas in advance of mining has been or is being introduced. The Chinese government has announced that, because of the coal industry's poor safety record and with thousands of fatalities resulting from methane explosions, it will invest 3 billion RMB (€300 million) into mine safety, especially methane drainage systems.

4.3.4 CMM utilisation developments

Because of the poor quality of much of the methane liberated from coal mines, which is to a great extent due to the lack of progress in introducing advanced methane drainage technologies, downstream technologies have been developed to either improve the quality of the gas or find means of viably using the low quality gas. The technological challenges depend on the gas quality: medium quality gas streams (25 – 90% methane) either need to be processed to increase concentration to pipeline qualities (96%+) or technologies that can use this gas must be developed or adapted; ventilation air (<1% methane) has significantly fewer markets but, as the largest source of methane, significant advances are underway to harness this energy.

4.3.4.1 Using Medium Quality CMM

Medium quality CMM frequently originates from gas drainage of the "gob," the mined out areas that are usually contaminated with large volumes of air from the working areas of the mine.

Technology or Parameter	Ventilation Air	Medium Quality CMM	High Quality CMM
Recovery Technique	Fans	In-mine Boreholes Vertical Gob Wells	Vertical Wells In-Mine Boreholes
Recovery Support Equipment	Surface Fans and Ducting	In-mine Drills and/or Surface Rigs Compressors and pumps	In-mine Drills and/or Surface Rigs Compressors and pumps
Heating Value	Low (Usually below 0.6% CH_4)	Medium (11-30 GJ/10^3 m^3) (30 – 95% CH_4)	High (35 37 GJ/10^3 m^3) (Above 95% CH_4)
Use Options	Combustion Air Flow Reversal Reactors Lean fuel turbines	On-Site Power Generation Natural Gas Pipeline Injection (After Upgrading) Gas to Liquids Direct use On-site Utility, Industry, district heating	Chemical Feedstock Pipeline Injection w.o. Significant Gas Upgrading Other Uses as for Medium Quality CMM
Availability	Available but some technologies not yet commercially demonstrated	Available	Available
Applicability	Mine sites	Widely Applicable Site Dependent	Technology, Finance and Site Dependent

DIAGRAM 15 – Utilisation options for different qualities of CMM

Source: Energy Edge

Also, some gas drained from coal panels (which typically is a high quality gas) faces significant reductions in methane concentration from leaks in the standpipe and in the pipeline to the surface.

Medium quality CMM may be used for local heating and cooking uses, or for the production of power. So long as the gas is at or above 25 – 30% methane concentrations, it is safe to use and poses few technical challenges, so long as the quality remains reasonably consistent. However, much of the medium quality gas can fluctuate in both quantity of supply and concentration. It also may contain harmful contaminants (such as water vapour, calcium, coal dust, etc.) that threaten the operation of gas engines or turbines for power production.

The alternative to finding direct uses that work for medium quality CMM is to improve the quality of the gas, whose principal contaminant is nitrogen. A number of different systems are on offer to remove the nitrogen and other contaminants, but these to date have been only applied in the U.S., where drainage technologies produce higher quality and quantity of gas making the incremental costs of upgrading competitive. At concentrations below 70% methane alternative uses are more competitive.

4.3.4.2 Harnessing Ventilation Air Methane

An estimated 17 billion cubic meters of methane is vented to the atmosphere from ventilation shafts, the greenhouse emissions equivalent of approximately 240 million tonnes of CO_2. Because of the low concentrations of all this gas, until recently attention has been placed on recovering and using the medium and high quality CMM. The first commercial use of ventilation air methane (VAM), however, was in 1995 when an Australian colliery introduced a slipstream of ventilation air as combustion air into 54 one-MWel engines that operate on drained CMM. This approach however is limited by its dependence on having a large combustion source near ventilation shafts.

Country*	2000	2005	2010	2015	2020	% Change
China	92.3	101.6	110.9	120.1	129.3	40.1
United States	36.0	39.8	40.6	41.1	39.9	10.7
Ukraine	30.1	37.5	41.3	42.3	43.2	43.3
Australia	9.5	10.5	11.6	12.3	13.6	42.3
Russia	9.2	10.8	11.2	11.6	12.0	29.7
South Africa	5.8	7.0	7.0	7.0	7.0	22.2
Poland	5.7	5.6	5.0	4.8	4.5	-21.6
Kazakhstan	4.5	4.7	4.7	4.7	4.7	5.5
India	4.0	4.5	4.8	5.1	5.4	36.1
United Kingdom	2.2	2.1	2.1	2.0	2.0	-9.6
Mexico	1.9	2.2	1.9	2.0	2.0	4.2
Germany	1.2	1.0	0.6	0.6	0.6	-52.7
Czech Republic	0.8	0.8	0.7	0.6	0.5	-42.8
Study Total	*203.4*	*228.1*	*242.5*	*254.2*	*264.7*	
Other Countries	33.7	37.8	40.1	42.1	43.8	
World Total	**237.1**	**265.9**	**282.6**	**296.3**	**308.5**	

DIAGRAM 16 – Global emissions of methane from mine ventilation shafts (Mt CO_2 equivalent)

Source: US EPA, 2003

One of the more robust technologies, flow reversal reactors can use up to 100 percent of all the methane from ventilation shafts, and the by-product, heat, may be used for the production of power or to satisfy local heating needs. These technologies employ the principle of regenerative heat exchange between a gas and a solid bed of heat exchange medium [see diagram 14]. Based on laboratory and field experience, flow reversal reactors may sustain operation with ventilation air with methane concentrations as low as 0.15%. Several demonstrations of flow reversal reactor technologies are making this approach ready for commercial deployment.

Key alternative means of using ventilation air that have not yet been commercialised but are being developed and demonstrated include putting VAM into lean fuel turbines, rotary coal fired kilns, and into thermal and catalytic flow reversal reactors.

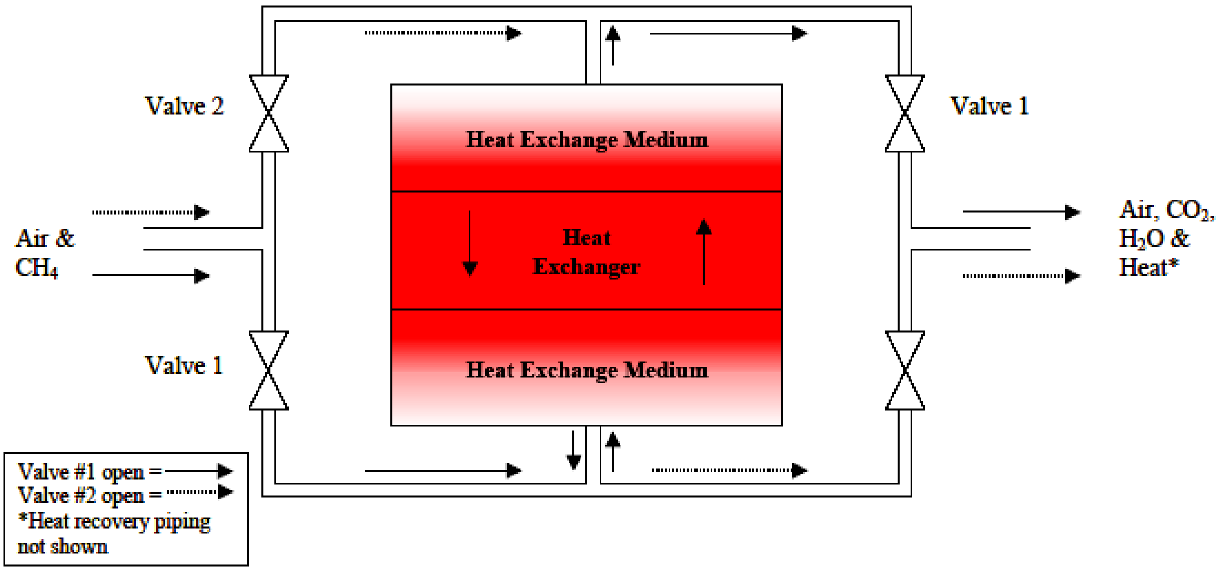


DIAGRAM 17 – Thermal flow reversal reactor

Source: US EPA, 2003

4.3.5 Cost analysis

Attention to coal mine methane has grown as concern has escalated for reducing greenhouse gas emissions. While compared to CBM the energy resource is small, CMM projects find their real value in the new greenhouse gas emissions markets.

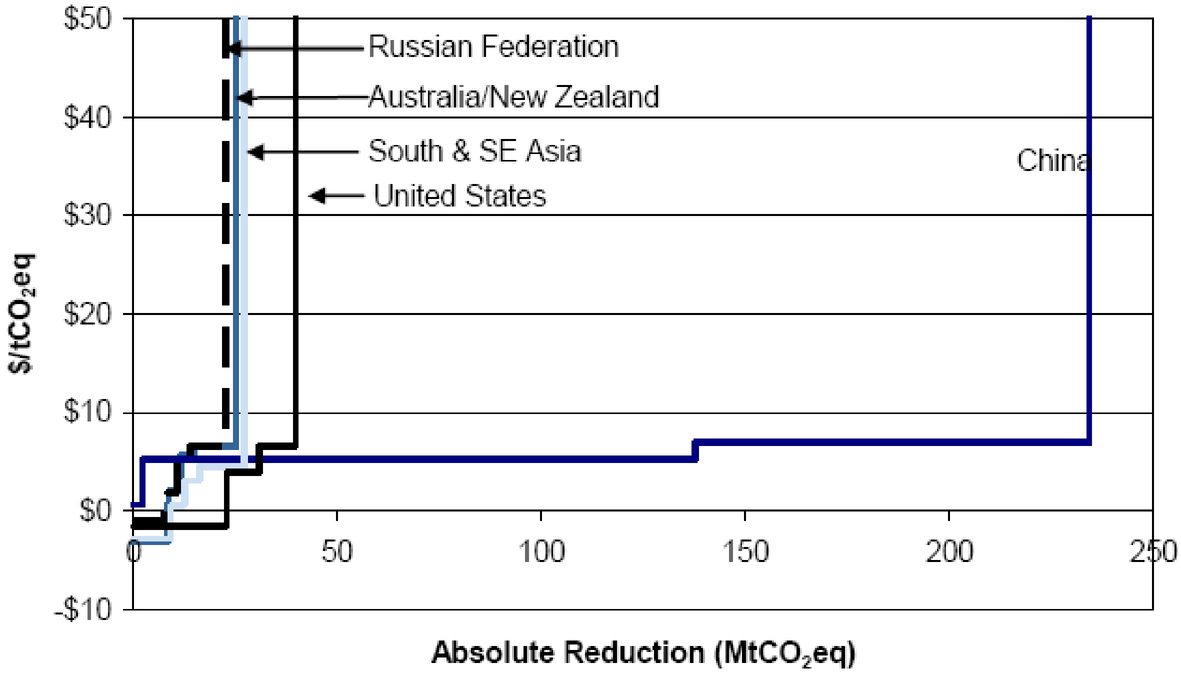


DIAGRAM 18 – Marginal cost of abating CMM emissions by region

Source: US EPA, 2005

CMM represents approximately 1.3% of human-induced greenhouse gases. The costs of reducing CMM are very competitive compared to many other sources. For example, the European Union Emissions Trading Scheme, which caps CO_2 emissions from utility and industrial facilities, is currently trading 2008 vintage allowances at around €16/t CO_2. Diagram 15 shows the results of global abatement cost analyses by the U.S. EPA indicate that less than 17% of global emissions (68 million tonnes CO_2 equivalent) could be reduced at zero or negative cost. At $15/t CO_2 (approximately €10.80/t) nearly 80% of global emissions, 325 million tonnes CO_2 equivalent could be economically abated. Therefore, against estimated worldwide methane emissions in 2010 of 400 Mt $C0_2$ equivalent, the following cost curve for reductions can be derived: 17% at no cost, 50% at USD 3.80/t, and 80% at USD 15/t. Regional differences in costs exist, but they are not significant.

A separate, technology specific analysis of the costs of reducing ventilation air methane emissions, shown below in Diagram 16, estimates that approximately 200 million tons CO_2 equivalent emissions could be reduced for less than $3.80/t (€3.20/t).

The rapid growth in demand for project-based emissions reductions, coupled with the low marginal cost of CMM projects, is resulting in a flurry of interest in CMM, especially in countries like China, Russia, and elsewhere. Barriers to implementing projects include unclear ownership/legal resource rights, delays in creation of frameworks for approving emission reduction credits, country investment risks along with the relatively small scale of most projects mean that not all of the theoretically economic projects will be implemented, but the trend clearly is for a rapid development of the global coal mine methane resource.

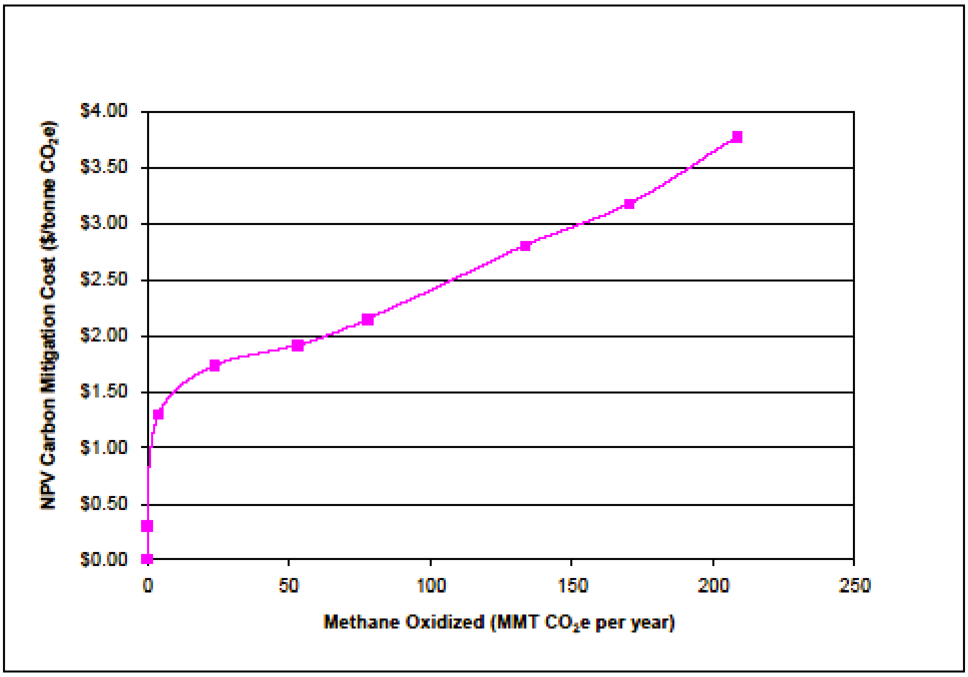


DIAGRAM 19 – Global marginal cost curve for reducing methane emissions from coal mines

Source: US EPA, 2003

4.4 Underground coal gasification (UCG)[3]

Underground coal gasification (UCG), uniquely, is gasification and a coal extract process combined into one step. A gasification process, in its widest sense, is the conversion of a fossil fuel to a gaseous product with a useful calorific value, whereas a coal extraction process is the winning of the coal from the earth's crust for energy conversion to useful heat, power or chemical manufacturing.

UCG, in other words, is the equivalent of a conventional mining and surface gasification without the disadvantages of coal handling, underground working or the need for a high-cost surface reactor. It is also a process with the potential to go deeper and access more coal resource than conventional mining, thereby increasing the world's coal reserve.

UCG is simply the gasification of coal in situ, and the reactions between oxygen, water and the coal are indistinguishable from those in a surface gasifier. A series of wells are required to access the coal, inject the oxidants and transfer the UCG product gas back to surface. The concept is deceptively simple and low cost although controlling the process, and producing a reliable and consistent gas has been the focus of development for many years. The main issue is whether the same gasification reactions can be made to work under the very different and geologically constrained conditions of the coal seam.

Since World War 2, the Soviets, Americans, Europeans and Asians have each had their periods of intense study of UCG and in some cases limited commercialisation. Most of the early projects, say before 1990, were eventually halted because security of supply had eased or natural gas prices were simply to low for UCG to compete.

The large body of evidence now built up from trials and commercial UCG operations shows that UCG can offer a viable commercial process to compete with surface gasification technologies. Syngas from UCG can be produced, almost certainly, at lower cost than surface

[3] This section has been complied with the assistance of an associate company, UCG Engineering Ltd.

gasification under the right conditions. The calorific value of the gas from the surface and underground processes are comparable, and gas composition is very similar.

4.4.1 Description of UCG resource

UCG may be a viable approach to extending global coal reserves, as it is possible to extract coal using UCG to greater depths and in situations where geological circumstances limit mine-ability. World coal resources have been estimated at around 6,000 BT[4], whereas the latest figures for proven coal reserve are 910 Bt[5]. This suggests that only 15% of resources are thought to be economically suitable for mining at current coal prices.

The only country where a UCG reserve assessment has been carried out, the UK showed a 17-fold increase in recoverable reserves if UCG was employed instead of mining. This indicates that the coal resource for UCG is 16.8 Bt out of a total estimated resource of 165 Bt, i.e. about 10% of the total coal resource is suitable for UCG. A country by country breakdown of the coal resource does not exist but is likely to vary considerably, as both economics and the ability to judge the total coal resource will be different in each case. In the absence of further data, we will assume that the additional coal reserve available for UCG is related to the proven reserve of each country by the formula:

Additional country reserve for UCG (Bt) = Proven County Reserve (Bt) x 6000/910 x 10%.

Country	Estimated available coal reserve for UCG Bt	Energy accessible in the UCG gas at surface PJ	Volume of gas available from UCG TCM	Volume of gas available from UCG TCF
Australia	54	210,000	18	620
China	76	300,000	25	870
Russian Federation	104	400,000	34	1,200
India	61	240,000	20	700
USA	163	640,000	53	1,875
Canada	4	15,000	1	45
South Africa	32	125,000	10	370
UK	17	65,000	6	200
Europe (excl. Russia)	86	335,000	28	990
Japan	0.2	780	0	2
Total All Countries	**597**	**2,300,000**	**194**	**6,900**

This is probably an underestimate of the UCG resource, but on a world basis the estimate amounts to an additional 600 Bt of coal, over and above the 910 Bt of proven coal reserve for mining, this is equivalent to an increase in reserve of 66%.

If UCG is employed to produce gas, the resource may exceed natural gas resources. The total volume gas available from the estimated UCG reserves for the leading countries studied is 6,900 Tcf (194 Tcm). This compares with a proven world gas reserve (BP statistical review 2006) of 6,300 Tcf (180 Tcm).

[4] World Energy Council, Survey of Energy Resources, Coal (incl. Lignite): http://www.worldenergy.org/wec-geis/publications/reports/ser/coal/coal.asp
[5] EIA 2005 estimated worldwide recoverable reserves: http://www.eia.doe.gov/fuelcoal.html

4.4.2 Summary of the energy and gas potential of UCG for key countries

The potential to add to proven global gas reserves by considering UCG is remarkable, as the below table demonstrates.

	Natural Gas Reserves	UCG Reserves (conservative)
Tcm	180	190
% of Natural Gas Reserves	100%	105%
Reserve/Production ratio of Natural Gas	67	70

This comparison, however, between proven gas reserves and UCG potential is a bit speculative. The (proven) natural gas reserves represent the amount of gas that can be extracted with current technologies and at current price levels, whereas the UCG reserves express an amount of gas that could be potentially extracted with current and near-future technologies, without taking into account the cost component. Several independent cost estimates have been conducted, and are discussed in Section 4.4.5 below.

4.4.3 Comparison of UCG and Natural Gas Reserves

4.4.3.1 UCG Technology

UCG in its simplest form consists of a coal seam and two boreholes, one for injecting gases and the other to remove the gaseous products, as seen below.

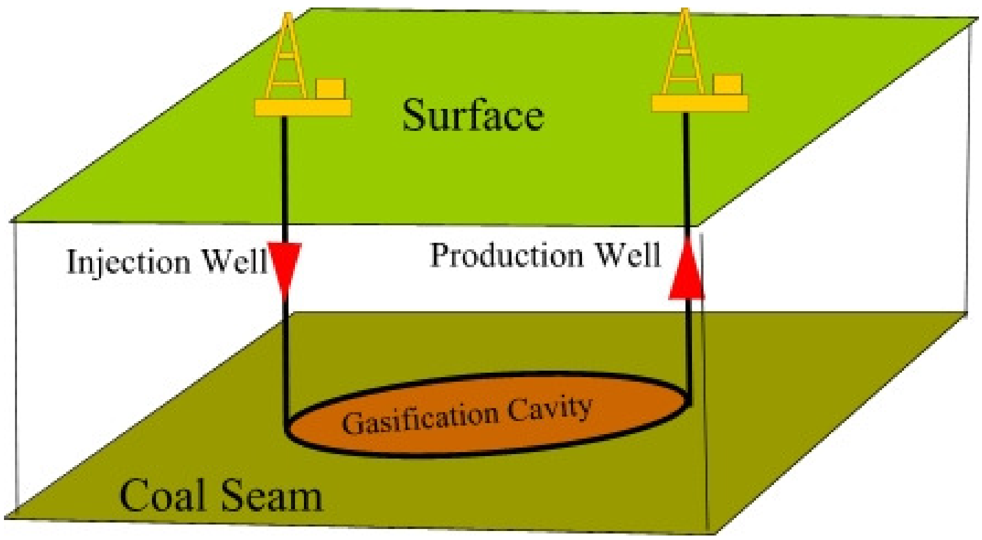


DIAGRAM 20 – Two borehole concept for UCG

Source: Energy Edge

A gasification cavity develops between the boreholes, in which the coal is gasified, the products migrate towards the production well and the solid products, char and ash are left in the cavity. In this simple arrangement, the ability of the coal to transport gases controls the reaction, but one of the problems is that coal permeability is generally low and notoriously unpredictable. The practical questions of ignition, cavity growth, and control of the process also have to be addressed.

The chemical processes of coal gasification are complex. The reactions take place at the surface of the coal and in the gaseous phase and include pyrolysis, partial oxidation and hydrogenation.

A description by Higman, et al[6] of the basic stages and kinetics of surface gasification apply equally well to the underground process and can be summarised as follows:

- Drying of the solid carbonaceous material and the production of water vapour.
- De-volatilisation at low temperature to drive off the lower hydrocarbons, tars etc.
- Reactions with the surface to form CO_2, CO and H_2.
- The methanation reaction, again at surface to form methane from carbon and hydrogen.
- A set of reversible reactions in the gaseous phase, dependent on temperature to effectively balance or move the composition of the gas towards equilibrium.

The particle size, the degree of mixing, temperature and pressure, the oxygen/ steam ratio, and of course the chemical and physical structure of the feedstock will all have an influence on the form and composition of the product gas.

The four basic reactions of gasification involving the solid carbon are:

$C + O_2 \Leftrightarrow CO_2$	(combustion reaction	– 394MJ/kmol)
$C + CO_2 \Leftrightarrow 2CO$	(boudouard reaction	+120MJ/kmol)
$C + H_2O \Leftrightarrow H_2 + CO$	(water gas shift reaction	+125MJ/kmole)
$C + 2H_2 \Leftrightarrow CH_4$	(hydrogenation reaction	- 67MJ/kmole)

Above the surface of the carbon, the reactions with free oxygen are essentially complete under gasification conditions, and the syngas reaches equilibrium by two further gaseous reactions:

$CO + H_2O \Leftrightarrow H_2 + CO_2$	(shift reaction	-41MJ/kmol)
$CH_4 + H_2O \Leftrightarrow 3H_2 + CO_2$	(steam reforming reaction	+206MJ/kmol)

The exploration and production of oil and gas has stimulated massively the development of drilling and completion. The drilling of lateral boreholes over distances of several kilometers in very deep wells, the use of completion tubulars for sour and high temperature gas and the technology for steering have all advanced rapidly. Research projects underway around the world are surveyed later in this section.

4.4.4 Commercial potential of UCG

UCG products may be viewed as desireable compared to conventional coal because they are less carbon intensive. The gaseous UCG products are well suited to the more efficient combined cycle for power generation. The UCG emission of CO_2 per unit of electricity is 0.8tonnes/MWhe, which is comparable with that produced by surface gasification in an integrated gas combined cycle (IGCC) plant and is some 18% lower than modern thermal plant. By comparison natural gas has about half the emissions of coal gasification. A switch to UCG from modern coal-fired plant is therefore a significant step towards carbon abatement for the coal lifecycle, before CO_2 capture and storage is even considered.

[6] Gasification, C Higman, M Van der Burgt, Elsevier Science, ISBN 0-7506-7707-4, 2003

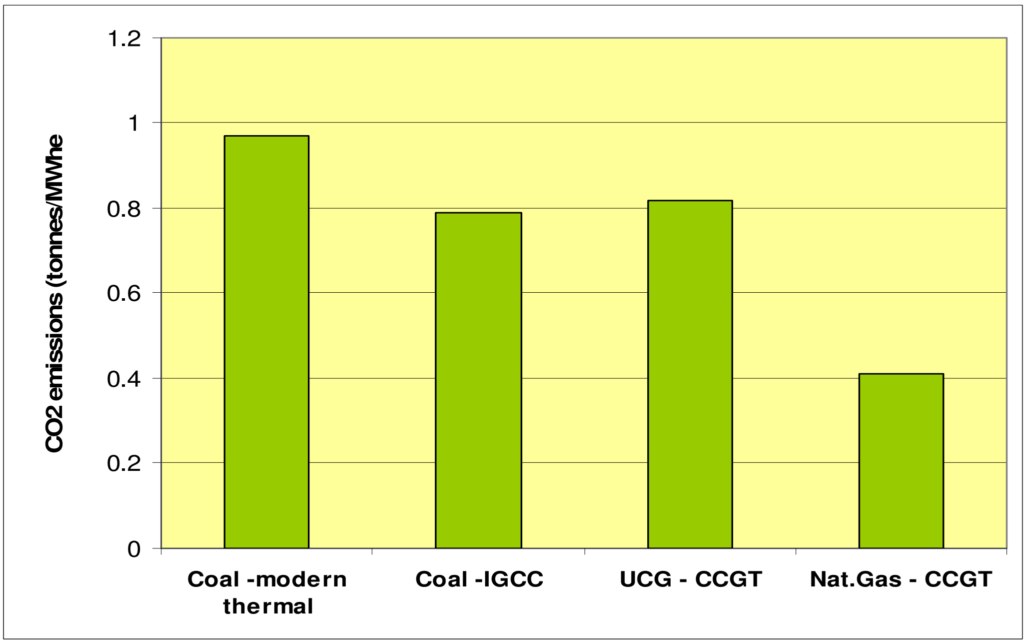


DIAGRAM 21 – Comparisons of CO_2 emissions for coal and natural gas

Source: DTI leaflet on UCG, 2002

The effect of progressive CO_2 capture on the emissions per MWhe produced is shown in the below figure. The scope for optimising the capture process is considerable, and emissions already low for coal can be reduced to those of natural gas combined cycle (CCGT) or removed to a level approaching renewable energy.

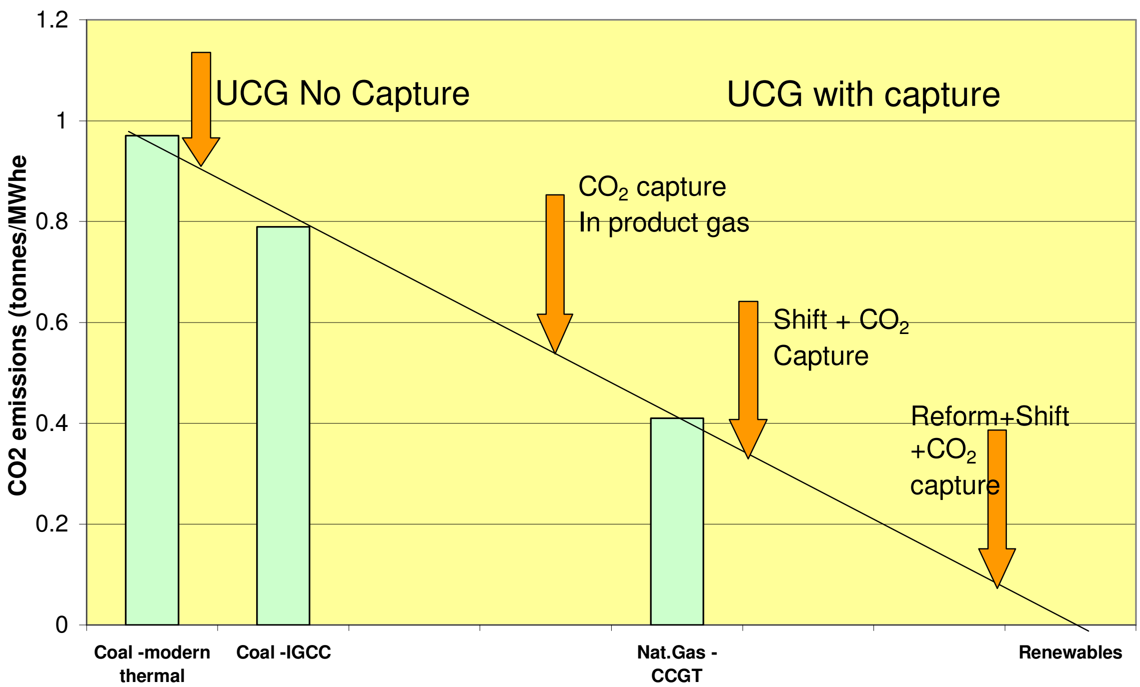


DIAGRAM 22 – Comparisons of CO_2 emissions from UCG and conventional power plant (assume 90% capture efficiency)

Source: DTI leaflet on UCG, 2002

The gas produced from UCG, after clean-up is perfectly suitable for industrial heating, the firing of steaming raising plant or co-firing in a power station. The first level of CO_2 removal raises the CV to about $19MJ/m^3$, which is half that of natural gas and similar both to manufactured city gas, which was distributed by the gas utilities before natural gas was introduced. Several of the trial sites in China distribute UCG gas, after rudimentary processing, to the local communities for cooking and heating.

Of great interest for sequestration projects is the fact that UCG doesn't take out all the coal; it burns flame paths 30m wide that leave coal behind in between. A rolling programme of UCG gasification along a coal seam would leave highly porous cavities and stressed strata in its wake. As these areas cool down, the abandoned cavities would be accessed by directional drilling or through the existing production boreholes. CO2 would then be injected at high pressure for storage and retention. For permanent CO2 sequestration, the depth and strata conditions must be suitable; this is an area for further investigation.

Coal gasification, both surface and in-seam, is at the forefront of cleaner coal technology. Utilisation of the product gas in combined-cycle gas turbines can provide significantly higher generation efficiencies, the gas can be cleaned and CO2 capture from Syngas using amine solutions is a well-proven technology.

The CO2 capture and sequestration option is now a topic of major research interest around the world. The US DOE has embarked on a large programme to support its "Pathway to Stabilisation" Scenarios

4.4.5 Current cost estimates

Independent cost analyses, performed in the UK and Australia, both indicate that UCG is competitive at prevailing energy prices.

4.4.5.1 UK DTI Cost Estimate

The UK Department of Trade and Industry (DTI) standard methodology for the assessment of the Cost of Electricity (COE p/kWh) from fossil fuel processes[7] was used together with the UCG assumptions for a scoping study of UCG, and UCG with CO_2 capture and storage (CCS). The results of the UCG analysis are summarised below.

7 CO_2 Capture and Storage – A win-win option, FES Report, No ED 01806012
AEA Tech plc, May 2003

Case	Cost of Electricity p/kWh		Comments
	No CO_2 Capture	Full/Partial CO_2 Capture	
UCG	3.2	-	Scale-scale UCG (50MW) – power plant on same site
UCG	1.9	3.5/2.0	Medium-scale UCG (300MWe) UCG station remote from power plant
IGCC(1)	2.3	2.9	Study by Jacobs Consultancy[8]
IGCC(2)	3.2	4.5	Early IEA study on capture options 2002[9]
IGCC(3)	2.8	3.4	Recent IEA study of CO_2 capture costs[10]
Natural Gas – Gas Turbine Combined Cycle (GTCC)	2.0	2.8	Standard case (2002) for NG combined cycle[11]

DIAGRAM 23 – Cost of electricity for power generation with and without CO_2 capture

Source: DTI leaflet on UCG, 2002

The above costs for the no capture case indicate that electricity production costs for UCG is comparable with Gas Turbine Combined Cycle (GTCC) at 2002 UK gas prices. Furthermore, natural gas prices to UK power producers[12] have increased by over 50% since 2002, which suggests that UCG would be significantly cheaper at present prices.

Coal fired Integrated Gas Combined Cycle (IGCC) costs are less certain and the three studies to date show a wide variation in likely costs both with and without CO_2 capture. On the basis of these estimates, the base case for UCG is at the lower end of the IGCC estimates for no capture, and in the middle of the range for power production with CO_2 capture.

4.4.5.2 CSIRO Cost Study

The recent economic assessment of UCG by CSIRO[13], Australia also compared electricity production costs for UCG and IGCC, under the energy supply conditions and costs in Australia. The assessment suggests that costs range from significantly lower to about the same level as surface gasification, depending on the effectiveness of the UCG process as defined by "good" and "bad". Of greater significance, is the fact that CO_2 capture is much more cost effective with UCG than surface gasification.

The difference between this result and that of those of the DTI is that the CSIRO study considered pre-combustion capture for CO_2 removal, whereas the DTI study only included post-gasification capture in the flue gases.

[8] Carbon Capture & Storage Gasification Assessment for DTI Cleaner Fuels Programme, Dec 2002
[9] Options for the capture of CO_2 emissions at power stations, IEA GHG Report PH3/14, February, 2000.
[10] Coal Power Plants with CO_2 capture: the IGCC option 7th IChemE Gasification Conference, May 2004.
[11] DTI report: *Options for a low-Carbon Future,* September, 2005
[12] Average prices of fuels to UK power producers , DTI Quarterly Energy Price Survey, June2005
[13] UCG: Evaluating Environmental Barriers, Exploration and Mining Report, CSIRO August 2004, currently unpublished

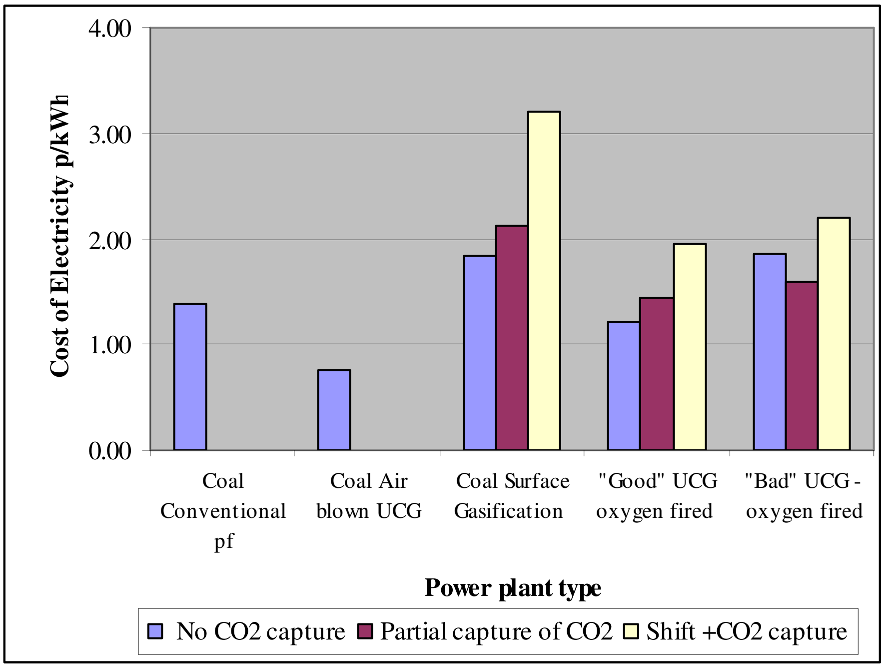


DIAGRAM 24 – Comparison of Cost of Electricity for UCG and Surface Gasification)
Source: CSIRO

4.4.6 Summary of international potential and research activity in UCG

UCG is mainly relevant to countries with indigenous coal resources. The three main centres of present activity on UCG are China, Australia and Europe. Others with an interest are India, South Africa, Indonesia, Pakistan, and the US.

Around the world, there are about a dozen field trials underway or being actively planned. These include a privately-funded project in Chinchilla, Australia, involving the production of gas from a deposit of high shallow ash, with the planned installation of a 30-40 MW power station; the installation by several mining companies working with the Beijing Mining Institute of inseam gasifiers in various shallow deposits starting in 1985; a commercial project at Yushno-Abinsk in Siberia producing a medium CV gas for heating and s steam for electrical generation; and a series of programmes ("Rocky Mountain") undertaken in the USA under the direction of the US Department of Energy, the Gas Institute, and several petroleum companies between 1978 and 1990. In addition, feasibility studies are being initiated in various countries. Several new commercial plants are in the planning stage around the world.

In the emerging countries, UCG is seen as a potential source of low-cost gas for distribution and power generation, whereas developed countries are interested in its potential for high efficiency power generation, CTL and UCG-CCS. Individual countries are now considered in detail.

The leading regions, for exploitation of UCG, are:

4.4.6.1 China

China has probably the lead market for UCG, and the greatest incentive, with few alternatives to meet its power and liquid hydrocarbon requirements. It is also well ahead already in establishing a technology base for UCG, although State intervention could help or hinder its development.

To date construction of in-seam gasifiers in China involves the use of underground mining methods. The Chinese UCG work has involved some 16 trials in shallow coal in various mining companies, and the programme is supported by the Centre for Underground Mining and Technology (CUMT), which has extensive laboratory facilities, including a 4m long test chamber for the simulation of underground tests. Not much is known about the success of the programme, apart from a few test results.

The State oil company, Petrochina is starting a deep-seam UCG field trial leading to commercial production in Liaoning Province, North East China. Seismic surveying and drilling for oil had identified a thick seam of deep lignite, which might be suitable for the UCG trial.

4.4.6.2 Australia

Local and Federal governments are favourable to UCG, and Australia has had a high profile project (Chinchilla) to establish a position in the technology, which is closest to commercialisation. The internal market for UCG syngas, however, is limited, and the case for UCG in Australia rests largely on developing an export market for gas-to-liquids (GTL).

The most reported project from Australia is the privately funded UCG trial project at Chinchilla site located west of Brisbane. An independent company using expertise and technicians from the former Soviet Union operated a trial for 30 months in shallow high ash coal. The trial produced over 80M $Nm^3$of gas with a CV of around 5MJ/ m^3 until the plant was mothballed in 2003. Commercialisation of the technology both at Chinchilla and elsewhere around the world is now being considered.

The latest plan for Chinchilla, announced in August 2005, involves the installation of a 30-40 MW power plant which will provide electricity to local markets. The second commercial phase of the Chinchilla project includes a 17,000-barrel-per-day Syntroleum CTL plant and an expansion of the power plant.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) have been doing research on UCG since the late 1990s, and classed the topic as a priority flagship project in 2003, which enables them to undertake additional studies of hydrogeology, process modelling, economics and public perception issues.

4.4.6.2.1 Europe

Europe is becoming increasing dependent on imported fuels as North Sea oil and gas reserves diminish. Economic reserves are relatively small, but there are vast quantities of deeper coal that could be exploited using UCG, if required. There is potential for UCG exploitation in most of Eastern Europe, although Poland and Ukraine have by far the largest reserves, but there is little interest so far. The UK coal resources, both on and off shore are the largest coal resources in Europe. UCG development has been identified as probably the only method by which the resource could be exploited in the short to medium term.

The UK has undertaken feasibility analysis for a deep UCG project under the Firth of Forth, has the technical and service industry support to create a UCG industry, and has already done much of the required environmental, economic and site evaluation feasibility work.

There are various reports from time to time of UCG investigations under consideration in Eastern European countries, like Ukraine, Bulgaria and Hungary. The most significant was a feasibility study by the Velenje Mining Company of Slovenia, into the possibility of UCG as a method of exploiting a large unexploited area of thick lignite.

Finally, Statoil of Norway has been interested in the possibility of offshore UCG as a long term option. They have recently mapped the coal deposits around the Norwegian coast.

5 FREIGHT MARKETS

Freight markets are difficult to predict in the long term (over five years) because the market is essentially a physical balance between ship numbers and availabilities and the number of ships that are required. Bulk carriers are getting larger and the rise of freight rates in 2002 and 2003 were created by very high demand (mainly from iron ore and metallurgical coal to China) and ship shortages that have since been largely corrected by new ship build.

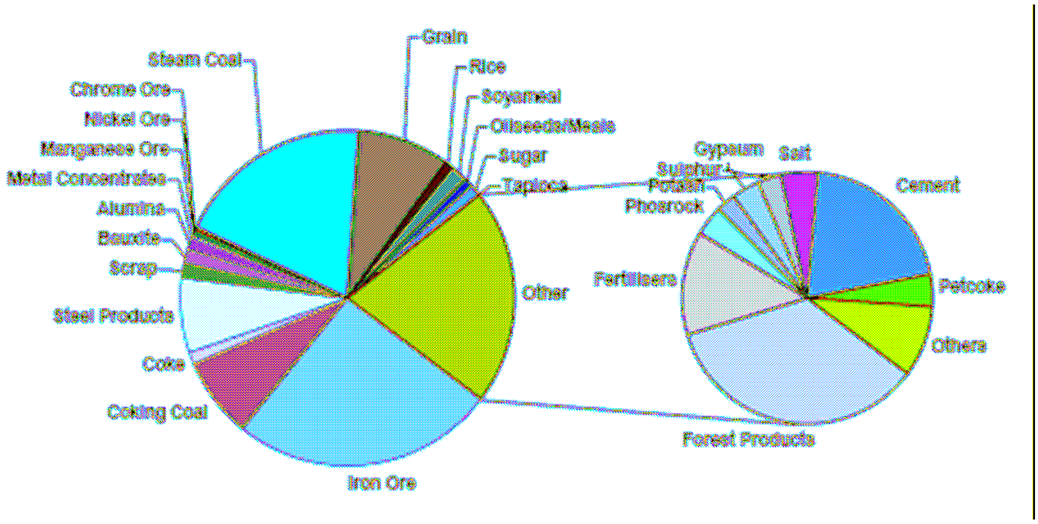


DIAGRAM 25 – Commodities in seaborne dry bulk freight

Source: Galbraiths

Just as the coal market has its drivers to determine availability and price, so the freight market has its own drivers that determine the costs. When the ship market is oversupplied compared to the freight to be moved, the cost is defined by the cheapest ships – the oldest, with fully depreciated costs. However, the market moves quickly as this will establish a new, lower freight rate.

Recent markets have shown that when there is a ship shortage there is no real ceiling against which prices are fixed. Steam coal and iron ore remain the dominant commodities but the change from thirty years ago is that at that time these two materials constituted nearly all the dry bulk market.

5.1.1 Fleet Structure

There are about 6,200 bulk carriers in the world and these are summarised below. It is becoming conventional to consider vessels up to 100,000 tonnes as Panamaxes as the vessel configuration allows them to transit the Panama Canal.

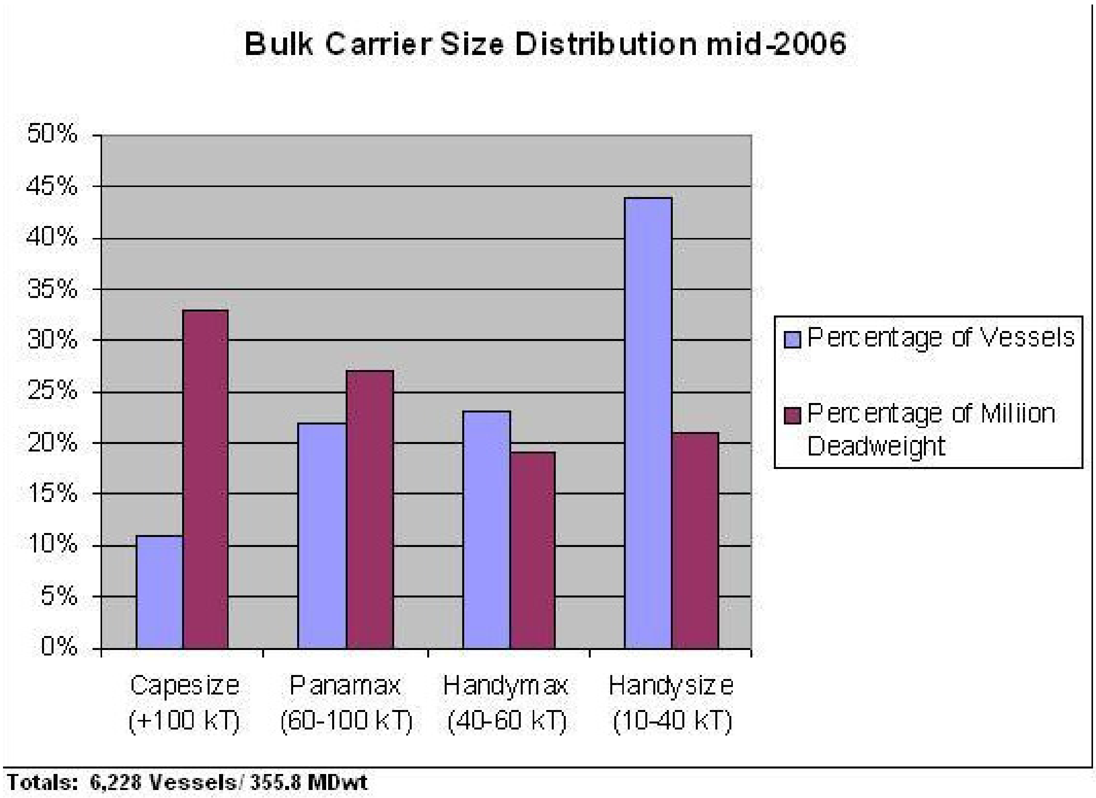


DIAGRAM 26 – Size distribution of bulk carrier fleet

Source: Energy Edge

The fleet age is determined by economics. There have been moves to increase bulk carrier safety by attempting to introduce a double-hull requirement but this has been rejected by the International Maritime Organisation (IMO).

The critical issue is the size of the fleet that is older than 25 years old. It can be seen that of the ship sizes, only a significant number of Handysize (up to 40,000dwt) vessels are in this category. The Capesize fleet, which carries the majority of the coal and iron ore cargoes, is very young, with three-quarters being less than fifteen years old.

5.1.2 Fleet Outlook

Although this outlook considers developments in the years ahead, it should be remembered that the market tends to be driven by very short-term factors that are often difficult to predict. Limited elasticity in feet supply and factors such as high port queuing levels mean that there is little to stop rates from rising sharply. This occurred in late 2003 when the daily rate for Capesize vessels rose from $10,000 per day to well over ten times that figure.

In terms of the order book for new vessels, the current level is about double that seen in 2002; a pre-cursor and primary factor in the subsequent high freight rates that prevailed in 2003 and 2004. The current and historical order books are shown in Diagram 17. It can be seen that Capesize vessels make up the bulk of the new build.

We think this is important. Analysis shows that significant numbers of Capesize vessels and Panamax vessels will enter the market in the next two years. The trend is to bigger ships and bigger ports, with central hubs in key destinations that may see faster turn around times.

This is reflected in the delivery schedule for the new build vessels. It shows that a large number of Panamax vessels are due for delivery in the next two years. This is because during the 2003 – 2004 freight boom, the Capesize vessels were fully occupied and this fact then threw a large portion of work onto Panamax vessels. It raises the issue of whether sufficient Capes are being built and if not this could throw more demand on larger Panamaxes

	2003	2004	2005	2006	2007	2008	2009
Handysize	49	60	65	67	65	46	38
Handymax	65	76	99	107	82	63	38
Panamax	18	76	75	112	99	56	27
Capesize	33	47	65	57	32	37	48

Source: Clarksons Research & Galbraith's Research Forecasts NB 2003-05 Panamax = 60-79,999 dwt and Cape = +80,000 dwt. For 2006-09 Panamax = 60-99,999 dwt and Cape = +100,000 dwt

TABLE 1 – Bulk Carrier New Builds

Source: Clarksons, Galbraiths

However, scrapping levels are low, almost non-existing in Capes in the last few years:

	2003	2004	2005	2006	2007	2008	2009
Handysize	68	14	15	23	45	50	55
Handymax	11	4	2	3	6	7	8
Panamax	5	0	3	5	10	11	12
Capesize	4	0	2	8	10	11	12

TABLE 2 – Bulk Carrier New Builds

Source: Clarksons, Galbraiths

5.1.3 Freight Markets

The table below illustrates the fleet tonnage capacity to 2010. There are no known orders for 2011 at this time and 2010 figures use previous averages.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Fleet at Start of Year	262	262	266	275	287	295	303	322	345	370	387	400	413
Additions	12	13	13	20	14	12	20	23	27	20	17	17	17
Scrappings	-12	-9	-5	-7	-6	-3	0	-1	-2	-3	-3	-4	-5
Fleet at End of Year	262	266	275	287	295	303	322	345	370	387	400	413	426

Derived from Clarkson Research Fleet Database (2010 = average of previous 14 years)

TABLE 3– Bulk Carrier Fleet in million tonnes

Source: Clarksons, Galbraiths

In modelling freight markets a number of complex interplays need to be understood. These include freight voyages per year, number of ballast voyages in between cargoes and trade patterns. History suggests that the industry achieves an average of eight cargo voyages per year. Also, the forecast is heavily dependent on Chinese iron ore demand, which is the single most important factor on cargo demand.

The surge in production as discussed elsewhere has been driven by China. Growth in Chinese crude steel production was around 33% between 1995 and 2000 but achieved an astonishing 175% in the period from 2000 to 2005 which is an annual average of a 22%. The first six months of 2006 indicate growth is still running at 18% but may just be slowing. Despite all the pronouncements by the Chinese government many of their plans to cool this demand have failed to deliver the promised results. However the forecast beyond 2006 is for the demand for iron ore to grow at a more measured pace in line with the forecast GDP growth of 9% or approximately half of today's number. Global iron ore demand is hovering around 7% but we anticipate this will decline in 2010 and 2011 to about 3%.

Global ore demand has also sustained the tightness in scrap availability. Ore cannot be recycled as scrap until it has been through its steel life cycle, which is some 10 to 15 years (or longer) into the future. As a result it is ore that must eventually satisfy the majority of the forecast growth in steel production. The recent growth in steel production and the rise of scrap consuming electric mills have effectively eliminated the scrap that had been stockpiled around the world. Additional steel capacity will be skewed towards ore consuming techniques, whether it is blast furnaces or the use of hot briquetted iron (HBI) and direct reduced iron (DRI).

The tables overleaf reflect a voyage rates forecast to 2010. Beyond that, considerable uncertainty exists due to lack of building orders and market risks that exists. However, we believe that little change from 2010 to 2011 will be seen as rates have declined by 2010 to historic levels

Indicative Capesize Rates												
	Richards Bay - ARA			Queensland - ARA			Puerto Bolivar - ARA			Queensland - Pusan		
	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low
Q3 06	12.8	15.1	10.5	15.7	18.6	12.8	12.4	14.7	10.2	9.9	11.6	8.1
Q4 06	12.1	14.3	9.9	14.9	17.6	12.1	11.7	13.9	9.6	9.4	11.0	7.7
Q1 07	12.5	14.7	10.2	15.3	18.1	12.5	12.1	14.3	9.9	9.6	11.3	7.9
Q2 07	12.8	15.1	10.5	15.7	18.6	12.8	12.4	14.7	10.2	9.9	11.6	8.1
Q3 07	10.4	12.3	8.5	12.7	15.0	10.4	10.1	11.9	8.3	8.1	9.5	6.7
Q4 07	11.1	13.1	9.1	13.6	16.1	11.1	10.8	12.7	8.8	8.6	10.1	7.1
Q1 08	11.4	13.5	9.4	14.0	16.6	11.4	11.1	13.1	9.1	8.9	10.4	7.3
Q2 08	10.1	11.8	8.3	12.3	14.5	10.1	9.8	11.5	8.0	7.8	9.2	6.5
Q3 08	9.0	10.6	7.5	11.0	13.0	9.0	8.8	10.3	7.2	7.1	8.2	5.9
Q4 08	9.7	11.4	8.0	11.9	14.0	9.7	9.4	11.1	7.8	7.6	8.9	6.3
Q1 09	10.1	11.8	8.3	12.3	14.5	10.1	9.8	11.5	8.0	7.8	9.2	6.5
Q2 09	9.4	11.0	7.7	11.4	13.5	9.4	9.1	10.7	7.5	7.3	8.5	6.1
Q3 09	8.3	9.8	6.9	10.1	11.9	8.3	8.1	9.5	6.7	6.5	7.6	5.5
Q4 09	9.4	11.0	7.7	11.4	13.5	9.4	9.1	10.7	7.5	7.3	8.5	6.1
Q1 10	9.7	11.4	8.0	11.9	14.0	9.7	9.4	11.1	7.8	7.6	8.9	6.3
Q2 10	9.0	10.6	7.5	11.0	13.0	9.0	8.8	10.3	7.2	7.1	8.2	5.9
Q3 10	8.3	9.8	6.9	10.1	11.9	8.3	8.1	9.5	6.7	6.5	7.6	5.5
Q4 10	8.7	10.2	7.2	10.6	12.5	8.7	8.4	9.9	7.0	6.8	7.9	5.7

TABLE 4– Indicative Capesize voyage rates – US dollars/tonnes

Source: Galbraiths

Indicative Panamax Rates												
	Qinhuandao - S.Korea			Qinhuandao - Japan			Puerto Bolivar - Hampton Roads			New Orleans - ARA		
	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low
Q3 06	5.9	6.7	5.1	6.4	7.3	5.5	9.4	10.9	7.9	12.2	14.2	10.1
Q4 06	5.5	6.2	4.7	5.9	6.7	5.1	8.6	9.9	7.2	11.0	12.9	9.2
Q1 07	5.6	6.3	4.8	6.0	6.9	5.2	8.8	10.2	7.4	11.3	13.2	9.4
Q2 07	5.7	6.5	4.9	6.1	7.0	5.3	9.0	10.4	7.5	11.6	13.6	9.6
Q3 07	4.8	5.4	4.2	5.1	5.8	4.5	7.3	8.4	6.2	9.3	10.9	7.8
Q4 07	4.9	5.5	4.3	5.3	6.0	4.6	7.5	8.7	6.4	9.6	11.2	8.1
Q1 08	5.0	5.7	4.4	5.4	6.1	4.7	7.7	8.9	6.5	9.9	11.5	8.3
Q2 08	4.6	5.1	4.0	4.9	5.5	4.3	6.9	7.9	5.9	8.8	10.2	7.4
Q3 08	4.2	4.7	3.7	4.5	5.1	4.0	6.3	7.2	5.4	7.9	9.2	6.7
Q4 08	4.5	5.0	3.9	4.8	5.4	4.2	6.7	7.7	5.7	8.5	9.9	7.2
Q1 09	4.8	5.4	4.2	5.1	5.8	4.5	7.3	8.4	6.2	9.3	10.9	7.8
Q2 09	4.3	4.9	3.8	4.6	5.2	4.1	6.5	7.4	5.5	8.2	9.5	6.9
Q3 09	4.1	4.6	3.6	4.4	4.9	3.9	6.1	6.9	5.2	7.7	8.8	6.5
Q4 09	4.2	4.7	3.7	4.5	5.1	4.0	6.3	7.2	5.4	7.9	9.2	6.7
Q1 10	4.5	5.0	3.9	4.8	5.4	4.2	6.7	7.7	5.7	8.5	9.9	7.2
Q2 10	4.2	4.7	3.7	4.5	5.1	4.0	6.3	7.2	5.4	7.9	9.2	6.7
Q3 10	4.0	4.5	3.6	4.3	4.8	3.8	5.9	6.7	5.1	7.4	8.5	6.3
Q4 10	4.1	4.6	3.6	4.4	4.9	3.9	6.1	6.9	5.2	7.7	8.8	6.5

TABLE 5 – Indicative Panamax voyage rates – US dollars/tonnes

Source: Galbraiths

6 LONG TERM COAL MARKET OUTLOOKS

6.1.1 Introduction

To understand the long term outlook for coal supply and demand, it is necessary to consider market drivers, of which the behaviour of power markets is the single most important factor, because such a high percentage of coal produced is used in this area.

Our outlook focuses on conventional coal supply; excluding the potential of underground coal gasification or coal mine methane. As noted in the sections of the report focussed on UCG and CMM, UCG has the potential to provide vast quantities of energy, whereas CMM, although contributing to energy supply, is principally interesting because it is a low cost means of reducing greenhouse emissions.

Key elements in future global supply and demand are productivity gains in mining and improved efficiency in combustion. As discussed in section 3.2.1, productivity growth per man and year is expected to continue. As to power generation, average world coal combustion efficiency in power stations approximates 32 %, while state of the art modern plant operates at 42% to 45%. Advanced clean coal combustion technologies promise efficiencies of 50 to 53 %. As new plants penetrate the market, efficiencies will rise and potentially dampen growth.

The World Energy Council estimates that by 2030, 72% of world coal-based power plants use advanced technologies with efficiency at 49 to 50%. Whilst this may, in theory, suggest coal demand will decrease it is likely that advanced plant will reinforce coal's traditional competitive advantages in terms of cost and supply characteristics that may result in declining market share being reversed.

6.1.2 Coal Quality

We have assessed the coal quality of the various coal deposits and do not feel future coal quality will be a dominant issue in the future markets. This is primarily because export markets will demand similar coal to that currently required. Much of the plant in existence will still be operational in twenty or thirty years time and needs will have to be met. If the power industry moves towards ultra super critical boilers coal quality will need to be maintained at or close to, current levels.

We do not envisage significant exploitation of low quality coals other than for new technology purposes. Export markets will be characterised by coals with heat vales at or above 5200Kcal (as received) for the foreseeable future. These needs have been emphasised by the difficulty lower quality produces, such as the Asam –Asam deposit in Indonesia, have found to break into traditional markets. The characteristics of such coals, with high volatile (>35%) and moisture (>30%) contents are not well-suited to traditional PF boilers, especially older ones that are typical in European markets.

In general we do not anticipate the demand for current coal qualities will fall significantly and believe export coal will maintain qualities at close to current levels; in domestic consumption a trend towards the use of sub-bituminous coals is likely, where their availability is good.

6.1.3 Coal Production Costs

In terms of coal costs, all major domestic markets appear to exhibit characteristics whereby coal prices remain stable. In the US, mine-mouth prices are predicted to rise slightly to 2010 and then decline slowly to 2025, but remaining within a range of $17-20 per tonne. The key to this is the belief that coal mine productivity will continue to improve, which is somewhat contentious in view of recent trends in the US and Australia. However, the industry and equipment manufacturers remain confident of further improvements which will keep coal competitive. The other significant issue is coal transportation. The vast sub-bituminous coal resources in Powder River Basin are mined at $5-10/t but are distant from markets. The key element in the US maintaining production costs is perceived improvements to transport systems that will reduce costs and improve efficiency.

The same opportunity exists for most major coal producers. Indonesia has little in the way of organised infrastructure, for example. Russia, China and India will all benefit from similar improvements if the necessary investments are made.

South Africa has potential to improve mining efficiencies although the rail system is excellent (current problems notwithstanding). Australia is probably the one country where further improvements in costs may be difficult, but port bottlenecks can be addressed and mining productivities improved.

Certainly, Australian costs are likely to rise in the future. The issue of infrastructure development is interesting because the traditional financial returns made by coal producers have been low, well under 10% return on investment. This has meant that large scale investments by mining companies have been undertaken with care and caution. Developments have happened, of course, in Colombia and Indonesia, but often the producers look to developments with state organisations, such as in South Africa (Spoornet) or Australia (Queensland Rail).

6.1.4 Regional Assessment of Future Coal Supply and Demand

Below is a summary of coal supply and demand. In all cases, we feel predictions to 2030 are reasonably valid but the period thereafter is more problematic.

Traditionally, coal markets have always been in a state of either over supply or close to over supply. This meant that whenever the coal price rose, producers were motivated to increase production to maximise profitability, which tended to send the market into over supply.

The long term issue is whether sufficient supply will exist to meet what we anticipate will be sufficient new coal sources for export markets. In essence, we believe that will be true until 2030 but new sources are limited – mainly from Nigeria, Botswana, Mozambique, Madagascar Alaska, Bangladesh and Pakistan.

6.1.4.1 Coal export markets

We anticipate coal export markets will remain in balance until 2025, beyond which predictions become subjective and unreliable. The market will see declines in production from certain traditional supplies – notably Indonesia and South Africa – but the entry of newer players that will be attracted by coal prices that we believe have made a step change and will remain higher than historic levels.

SEABORNE THERMAL COAL EXPORTS (mt)

REGION	COUNTRY	2005	2006	2007	2008	2009	2010	2011	2015	2025
ATLANTIC	South Africa	74	71	71	73	76	78	80	75	60
	Colombia	55	58	62	63	64	66	68	75	95
	Russia West	40	45	48	50	52	53	55	60	70
	Poland	14	12	10	8	6	5	5	5	0
	USA/Canada	6	6	6	6	7	7	7	10	25
	Venezuela	8	8	8	7	7	7	7	10	10
	Norway (Spitsbergen)	1	1	1	1	1	1	1	0	0
	Southern Africa	0	0	0	0	0	0	0	5	15
	Nigeria	0	0	0	0	0	0	0	5	10
	SUB TOTAL	198	201	206	208	213	217	223	245	285
PACIFIC	Australia	112	118	125	135	145	155	165	200	280
	Indonesia	130	147	154	155	155	155	150	140	110
	China	60	58	58	58	58	58	58	50	35
	Russia East	10	11	12	13	16	20	22	25	30
	Vietnam	0	0	0	1	3	5	7	15	40
	Alaska	0	0	0	0	0	0	1	5	10
	Bangladesh	0	0	0	0	0	0	2	5	10
	Mongolia	0	0	0	0	0	0	2	10	15
	SUB TOTAL	312	334	349	362	377	393	407	450	530
	TOTAL	510	535	555	570	590	610	630	695	815

SEABORNE THERMAL COAL IMPORTS (mt)

REGION	COUNTRY	2005	2006	2007	2008	2009	2010	2011	2015	2025
ATLANTIC	UK	37	39	38	35	35	35	35	35	25
	Germany	24	26	26	28	30	32	32	35	40
	Spain	21	19	17	18	19	20	20	20	25
	Italy	17	18	19	19	19	20	20	25	30
	France	11	9	10	10	10	10	10	10	10
	Netherlands	10	10	10	10	10	10	11	15	15
	Other EU	24	24	23	22	22	21	21	25	30
	Israel	13	13	13	13	13	13	14	15	15
	Turkey	10	9	9	9	10	10	10	10	15
	Med/North Africa	7	7	7	7	8	8	9	10	15
	USA	26	30	35	38	38	40	42	50	60
	Other America	10	11	11	11	11	11	11	15	20
	SUB TOTAL	210	215	218	220	225	230	235	265	300
PACIFIC	Japan	113	113	113	115	115	116	117	120	130
	South Korea	59	62	67	70	72	75	79	85	100
	Taiwan	52	54	54	55	55	55	55	55	55
	India	24	31	34	38	42	46	50	60	80
	China (incl. Hong Kong)	17	22	25	25	28	31	34	40	60
	Malaysia	10	11	14	15	18	20	21	25	30
	Thailand	7	8	10	10	12	13	14	15	20
	Other Pacific	9	9	9	10	10	10	10	10	15
	Cent / South America	9	10	11	12	13	14	15	20	25
	SUB TOTAL	300	320	337	350	365	380	395	430	515
	TOTAL	510	535	555	570	590	610	630	695	815
OVERLAND	CIS/East Europe/America	60	62	64	66	68	70	71	75	85

DIAGRAM 27– Summary of long term export supply demand balance

Source: Energy Edge

This reflects on future CCT projects in Europe and Asia where coal is not found in deposits that can be exploited (to any great extent) by conventional mining – notably Japan, Korea and Taiwan. Only three countries in the world have coal resources that, in our opinion, are extensive enough to provide cheap (probably under $15 per tonne ex-mine) coal supplies for a range of uses including traditional PF use and CCT. These are the USA, Russia and India. China has reserves that are adequate only to about 2030 and although significant coal deposits exist, considerable exploration and mining at depth (with associated major capital investment) will have to be undertaken this then reflects on the financial return CCT projects will supply and whether high capital costs for new projects will be justified. The world-wide average investment for coal projects is currently about $30 per sales tonne produced but this may have to increase and the costs passed onto the consumer.

6.1.4.2 Major domestic markets

We have divided the countries in Tier 1, Tier 2, Tier 3 and Tier 4 countries reflecting the impact of coal availability on them.

Tier 1 Countries – self-sufficiency and more

North America

Coal demand will increase steadily until 2030 at an annual rate between 0.5% (low case) and 1.5% (high case). This will result in total demand of between 1.2 and 1.5 billion tonnes by 2030. After this, it is likely coal production will level out as we anticipate the investments the US is making into alternative energy technologies come to fruition.

The US has such massive reserves – conservatively, at least 100 billion tonnes of extractable coal – that it is capable of meeting possible demand until well beyond 2050. It is likely a shift will occur back to Appalachian and Illinois Basin from the western reserves as sulphur emission will be less of an issue at the end of the next decade when all boilers have scrubbers fitted.

The declining availability of natural gas in the US is a real concern for the US. LNG will increase in use but it will need to remain cost-competitive when compared to coal.

The massive coal reserves are well-placed to utilise exploitation for coal gasification, a technique under careful assessment in the US.

Whilst both the US and Canada will continue to export coking coal, their influence in markets and their focus will remain satisfy electricity production demand.

Russia

Russia is the other country in the world with huge demands but also huge resources, the difference with the US being the fact that it has extensive oil and gas resources as well as coal. With some 50 billion tonnes of hard coal and double that in lignitic reserves, it is clear that the coal reserves are sufficient to meet low and high case demands, which average at 400Mt by 2020 and 700 Mtpa by 2050.

The key is the reserves in the Kuzbass and the ability to meet future demand. We believe the reserves are adequate to improve existing mines and develop new ones. There are challenges for the industry, in re-structuring, improving productivity and overcoming technical issues. The exploitation of the eastern coalfields will continue to meet internal demand primarily. As to exports, much depends on demand and pricing to justify the infrastructure issues that need to overcome. The potential clearly exists and, in light of potential shortfalls in European supply, Russia is targeting this market in preference to Asia with 45 Mt seaborne thermal going to Europe versus on 11 Mt to Asia.

Finally, the potential exists in Europe for the development of a very low sulphur coal market during the derogation period of the Large Combustion Plant Directive (2008-2015) of up to 10 million tons per year. Russia is the only country capable of supplying high CV, very low sulphur (<0.3%) coals to meet demand, which may encourage further development of export infrastructure.

Tier 2 – Prime exporters

Australia

Australia has very substantial coal resources, over 40 billion tons, which are reasonably close to the coast and comprise both coking and thermal coals. The deposits are of consistent quality and capable of meeting increased demand in Asia's markets. However, new developments will require more infrastructure as mines will move further inland and, in some cases like Wyong, deeper (below 40m). Essentially, though, the reserves in Australia are capable of meeting export needs until 2030 and beyond. Australia is blessed with some of the finest coal deposits in the world and the country produced almost 300 million tonnes of hard coal in 2005, mainly from Queensland and New South Wales. Over 170 million tonnes was produced from about 40 operations in Queensland and 120 Mt from New South Wales. In Queensland, some 85% of the coal is produced by opencast methods and the products are split roughly half and half into coking and steam coal, coking coal being slightly in the dominant position.

In Queensland, the Bowen Basin is the most important producing region. The most important Permian coal basin is the Bowen Basin, which is exposed in a large, triangular-shaped area of central Queensland, 600km long and up to 250km wide. The basin extends south in the sub-surface beneath Mesozoic sediments of the Surat Basin, and connects with the Gunnedah and Sydney Basins in New South Wales.

Coal seams in the Bowen Basin exhibit major variations in rank and quality, reflecting both the depositional and tectonic history of the basin. A broad trend of increasing rank from west to east has long been recognised, and was used as a guide for coal exploration targets during the late 1950s and early 1960s.

In New South Wales, the Sydney Basin is divided into four commercially important coalfields, the Newcastle, Hunter, Southern and Western, with the three outlying basins (Gunnedah, Gloucester and Oaklands) of lesser importance.

Total resources amount to approximately 8 billion tonnes. These reserves are contained within 56 operating mines and colliery holdings and 30 major development proposals. The major coal deposits in NSW range in rank from bituminous coking and thermal coals; to sub-bituminous thermal coals. The quality of thermal coals ranges from medium-to-high ash, low sulphur coal used for domestic power generation and cement manufacture; to medium to low ash, high energy and export quality coal. Prime, low volatile, hard coking coal and low ash, semi-soft coking coal, used for iron and steel production, supply both the export and domestic markets. The rail network servicing the NSW export and domestic coal mines extends more than 1050km.

Domestic demand, focussing on lower quality coals and lignite will easily be met, even if Australia’s natural gas resources deplete as quickly as anticipated.

Colombia

Essentially, Colombia has extensive coal reserves. Colombia has reserves of just over 6 billion tonnes located in thirty five coaliferous basins, of which eight are currently exploited. Currently, the Cerrejon and La Loma basins are the focus of production from opencast means. Although there are reports of coal quality issues in the longer term, post 2015, as a result of increasing ash contents, Colombia is well set to meet any realistic demand in coal exports until at least 2030. Again, infrastructure will be the key in developing the resources and political issues will play a role but we estimate Colombia has the capability, from a reserves perspective, to meet possible demand levels at least until 2030 and potentially beyond that.

Infrastructure expansions are planned by both major mining operations (Drummond with La Loma and a consortium of Xstrata, BHP Billiton and Anglo American at Cerrajon Coal Company).

Indonesia

Indonesia has extensive low quality coal deposits that the government has been actively promoting as a fuel source for many years. There is much to be done to develop mines to meet coal-fired demand on Java but there is little doubt the reserves will exist. Export demand has taken priority primarily because of the high financial returns generated in the past three years.

Both the power sector and cement sectors can adapt to take coal qualities that will not be acceptable into conventional export markets. The other factor is domestic demand for coal in Indonesia as the country tackles the acute power shortages on Java. Over twenty coal-fired plants are planned to be on line by 2015, totalling 15 GW of new power, all sourced from local coal, albeit probably low-rank coals. This will limit Indonesia’s ability to increase exports significantly and we feel the country is already close to its eventual limit. The programme is termed 'electricity crash programme' by PLN, the state utility company. Four plants are currently out to tender totalling almost 2GW. This suggests coal-fired capacity will increase to about 20GW by 2011, although this is ambitious given Indonesia's track record of under-achievement.

We anticipate internal demand for coal will double from 42mtpa in 2006 to 82mtpa by 2011. This may be unsustainable as with export coal levels sitting around 150mtpa the total mine capacity seems unlikely to extend beyond 210mtpa, creating a shortfall of 20-30 mtpa. Although new, unplanned mines are possible; this is unlikely in the time frame under consideration.

However, there are number of issues facing Indonesia and its attractiveness as an investment destination. These include:

- Potential abandonment of the trusted Contract of Work system for mine exploitation for a method whereby any foreign investment is made though a joint venture with state-owned mining entity – a change that might be expected to encourage foreign investment, but which instead could make it less attractive because of administrative shortcomings.
- Changes to the Tax Code will potentially detrimentally affect mining.
- Incidence of illegal mining, a problem in several areas, especially South Kalimantan.

The attractiveness of the Indonesian mining sector has diminished for foreign investors since the original Coal Contract of work was issued in the late seventies. The first generation of the CCOW allowed foreign ownership of mining rights and activities but there was a requirement to sell 51% of the shares in the controlling company after 15 years of production, although legal discussions often delayed this. This resulted in ten mines starting production, being mainly the existing large producers. The second generation was closed to foreigners and the third, in 1997, resulted in many areas being studied by, whilst held by Indonesian companies, few mining activities have actually occurred. In this version, the requirement for holders to sell down is much less, but it is problematic for foreign entities to be awarded the contracts.

The CCOW is now in its fourth generation and reflects new mining laws that have been implemented since the fall of the Soeharto government in 1998. The sector has seen little growth in investment since the economic troubles of the late 1990's and the divestment of power to the regional governments has resulted in some problems with the implementation of new mining laws.

Tax structures are not conducive to investment, academic experts and industry representatives have cited the government's tax policy on coal as a major disincentive for investment in the sector. Corporate tax rates, royalty payments and value added taxes (VAT) are among the highest in the world at almost the double of South Africa and more than 1.5 times of those in China and Australia. The net effect of these policies, as well as continued delays in producing a new mining law, has been a steady drop in investment in the coal sector. In December 2005 the Coordinating Ministry for the Economy agreed to implement Ministry of Finance Decree No.95/2005 to impose a coal export tax of 5 percent to secure supply for domestic needs. This has subsequently been overturned in Indonesia's courts and now the level is at 0%.

A 2005 World Bank study found that it takes an average of 151 days to start a business in Indonesia. President Yudhoyono has promised reforms to reduce that period to just 30 days. The GOI has drafted a new investment law and accompanying regulations aimed at streamlining Indonesia's investment procedures and moving from an approval to registration system.

Coupled with a lack of coal resources that have suitable potential, Indonesia has declined as an investment destination. Government control is unlikely to grow stronger, there seems a general acceptance that it too high, but as the recent attempts to increase taxation (which appears to be aimed at getting a high direct share of high export prices) there is always the potential for ill-advised government interference.

Tier 3 – Adequate to meet domestic demand

India

India is well endowed with extensive reserves but coal qualities and mine productivity are low. The potential to meet domestic requirements is high but the industry requires a complete re-organisation and reinvestment. Coal qualities are poor with low CV's and high ash contents. However, the technology for using such coal is well proven (in South Africa, Eskom have utilised coals with up to a 50% ash content). The projected shortfall in coal supply and demand is a result of infrastructure issues, chronically low productivities and transport issues.

India produced 390Mt of hard coal in 2005. Moreover, lignite mines produced 30 Mt. Although coal production has increased at rate of about 5% per year it has not kept pace with power demand which has increased at 6-7% annually. 90% of the production of India is from Coal India Limited (CIL), the state-owned monopoly.

India has the reserves to meet coal demand but significant development is required and in the meantime its thermal coal imports are expected to rise from 30 Mt now to 60 by 2015.
All the coal mined is used in India and the country is increasingly looking to imports to satisfy demand. Oil reserves are low in India (6 billion barrels) and 70% of its oil needs are met through imports. Coal remains the dominant energy source and this is reflected in the fact that 67% of its electricity needs are met by coal. Gas reserves are to be over 500 MToe and production is 20 Mtoe per year.

However, demand in both steel-making (currently 13% of total coal used) and cement manufacture (4% of coal mined) is growing at a faster rate than coal production.

Current coal shortfalls in India are estimated to be about 20 Mtpa and this is slated to grow to 80 Mtpa by 2011. On top of this, over half of India's coal is moved by rail and the requirement to move coal large distances is growing, straining India's capability to supply coal.

Distance/ Tons Moved	1996-7	2001-2	2006-7	2009-10
Pithead	70mt	109mt	128mt	155mt
<500 km	50mt	51mt	55mt	70mt
500-1000 km	50mt	95mt	170mt	215mt
>1000 km	200mt	285mt	400mt	500mt

Coal's share of electricity generation in 2020 will reduce only slightly to about 68%, with power demand increasing from 530 TWh in 2000 to about 1500 TWh in 2020. The Planning Commission see likely coal demand ranging from 550-680 Mt by 2020, almost doubling current production, coal retaining its position as oil and gas grow more slowly and renewables make a modest contribution. Coal requirements are expected to exceed 750 Mt by 2030.

We do not envisage that environmental legislation will impact significantly on coal's use although power plants will improve their operational efficiency by 2-3% as more coal is beneficiated and better equipment installed.

P.Shukla, T. Kram and T. Hamacher considered India's future energy supplies and the possible role of fusion in the future and concluded that coal will remain dominant throughout this century, although we question the suitability of India's coal reserves and capability to mine then after 2030. Diagram 23 represents supply by sector on a non-constrained CO_2 basis

The Central Mine Planning and Design Institute report that only about 20%, 52 billion tonnes, of India's total reserves may actually be mineable. The Energy Resources Institute (TERI) have calculated, on this basis that the depletion of older mines, the slow development of new operations and lack of mineable reserves may limit Indian production to 500Mtpa. As an example, we have experience of one deposit which in theory holds several hundred million tonnes of coal in a 17m thick seam dipping from 40m to 300m below surface. In practice, mining such a seam by longwall methods (opencast is not allowed due to the surface being protected forest) is possible but highly complex, using methods rarely used in the world. The real viability of such deposits is highly problematic.

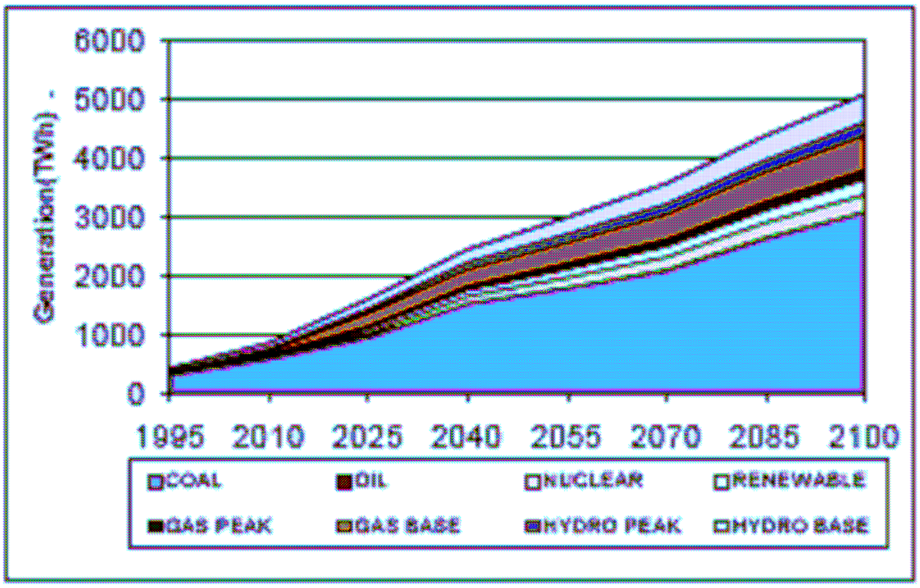


DIAGRAM 28 - Possible future energy supply in India

Source; Shukla et al

Pakistan

The first assessment of coal reserves of Pakistan was made in 1950 at 500 million tones in all four provinces, revised to 824 million tonnes with increased discoveries in 1986. The coal resources were estimated at 9 billion tonnes in 1989 (Kazmi & Siddiqi 1990). Sindh province is the main source of thermal power for Pakistan, in future. Thar coal field is the largest in Pakistan, contains lignitic coal with sulphur at 1.5%, ash 15% and moisture 45%. A contract has been signed between Government of Pakistan and a Chinese public company for the development of one evaluated coal block at Thar Coal Field and commissioning power plant. The Government of Sindh has also signed an MOU with an Australian firm for in-situ gasification and the commissioning of a 1200 MW power generation plant on another evaluated coal block.

Lakhra Coal Development Authority (LCDC) was incorporated as a public limited company in 1990. The company is a joint venture of Pakistan Mineral Development Corporation (PMDC), Pakistan Water and Power Development Authority (WAPDA) and Government of Sindh. Its prime responsibility is development and commercial exploitation of Coal deposits of Lakhra Area, Sindh. LCDC holds a mining lease of 621 sq. kilometers, having proved reserves of 150 million and estimated 2000 million tonnes. It has mined about 329,198 tons of coal during the year 2001-02 out of which 221309 tons was supplied to WAPDA. There are several power initiatives under discussion but no firm plans as yet.

COAL RESOURCES OF PAKISTAN

Province/ Coal field	Coal Resources (million tones)				
	Measured	*Indicated*	*Inferred*	*Hypothetical*	*Total*
SINDH					
Lakhra	244	629	455	--	1,328
Sonda-Thatta	60	511	2197	932	3,700
Jherruck	106	310	907	--	1,323
Others	82	303	1881	--	2266
Thar	3,407	10,323	81,725	80,051	175,506
Sub-Total	**3,899**	**12,076**	**87,165**	**80,983**	**184,123**
BALOCHISTAN					
Khost-Sharig-Harnai	13	--	63	--	76
Sor-Range/Degari	15	--	19	16	50
Duki	14	11	25	--	50
Mach-Abegum	9	--	14	--	23
Pir Ismail Ziarat	2	2	8	--	12
Chamalong	1	--	5	--	6
Sub-Total	**54**	**13**	**134**	**16**	**217**
PUJNAB					
Eastern Salt Range	21	16	2	145	235
Central Salt Range	29	--	--		
Makerwal	5	8	9		
Sub-Total	**55**	**24**	**11**	**145**	**235**
GRAND TOTAL	**4,008**	**12,113**	**87,189**	**81,144**	**184,575**

(Source: World Energy Council).

Tier 4 –Potential shortfalls in coal supply

World trade in hard coal is slated to grow to above 1 billion tonnes by 2030, with steam coal growing faster than coking coal so that by 2030 it will form over three-quarters of the market.

The key is: does the world have the resources to sustain such demand?

China

We calculate that China has 30 years of life in hard coal reserves and it is difficult to see if production can be maintained at over 2 Btpa past 2030 or 2040, which will focus attention on technological change, including nuclear and use of low quality, expensive-to-mine coal deposits.

Europe

Consistent demand coupled with declining production could produce a potentially significant shortfall in supply and demand profiles by 2015. UK will be producing below 10 Mtpa, Germany will produce about 10 Mtpa of hard coal and Poland will at best be meeting its needs but is more likely to be importing coal. Between 2015 and 2020, South Africa may well have declined as an exporter to a level below 60 Mtpa. Colombia may well be exporting significant tonnages into the US if the required mine developments there have not happened in time to meet demand growth. It is interesting to note that the additional growth in exports from CCC in Colombia from 2004 to 2008, about 4Mt will all head into the US.

By 2015 we forecast a reduction in domestic hard coal tonnage;

UK	**- producing about 10 Mt (-10 Mt from today)**
Germany	**- producing about 10 Mt (-20 Mt from today)**
Poland	**- producing about 80 Mt (-20 Mt from today)**

This would suggest a total deficit of nearly 50 Mt by 2015, if demand is consistent with today's levels, and by 2020 this could be 80Mt, as South Africa slows its export production. Post 2020, we believe South African exports could decline quickly to a level of 40-50 Mtpa, which could have a dramatic effect on coal supply if customers do not plan adequately.

This suggests that only Russia and Colombia will be able to react adequately to such a potential shortfall as we believe Asian markets will not be in a position to ship significant tonnages to Europe. The US may re-enter the export market, especially post-2015 when sulphur restrictions will be a thing of the past in Europe as all plants will have scrubbers fitted but this will depend on the domestic markets and the ability to divert coal.

If demand stays consistent – and the EU's view is that it will – countries reliant on imports, notably UK and Germany (especially as the latter is committed to coal-fired power) will be vulnerable to tight coal markets as the imports are not capable of replacing domestic production.

As in any market there are a series of potential factors that may allow the situation to be relieved, notably;

- Coal price rises consistently enough (and stay at a level probably above $40 FOB) to allow the exploitation of new South African deposits, especially the Waterberg
- Nigeria develops a coal industry
- Russia substantially increases exports, perhaps to over 80 Mtpa
- Colombia improves its infrastructure and exploits more deposits
- Venezuela develops into a large, reliable coal supplier

- Technology advances, especially in in-seam gasification, reduce coal demand and render self-sufficient in energy

Asia

Asian steam coal demand is set to grow at 2-3% virtually throughout the forecast period. On the face of it, the coal reserves in the region are adequate to meet demand but there are important issues;

- China will decline as an exporter slowly (some would disagree and believe the country will exit the export market as quickly as they entered it) and create a shortfall in tonnage
- South Africa, as the swing supplier, will have limited flexibility after 2015 and from 2020 may decline rapidly.
- Indonesia will probably see exports decline from 2010 onwards as existing operations come to the end of their lives. With the market showing no real appetite for low CV coal below that traded currently by PT Adaro, development of new resources, even if ready to come on stream, Australia has the coal reserves to meet increased demand but probably cannot do it alone and will be dependent on significant infrastructure developments. If Indonesia and China are declining as exporters, we feel that Japan, Korea and Taiwan are at risk from coal shortages post 2010 and certainly post 2020.
- India's situation seems destined to exacerbate pressure on coal supplies at least until 2010, with a significant shortfall that will be made up by imports. Longer term, India will seek to develop its own resources but to do so effectively will require massive industry restructuring and the use of modern boilers capable of utilising the high-ash, low CV coals that dominate the reserves.
- New supply sources are possible and we have noted potential in Pakistan, Mongolia, Bangladesh will be slow and probably focussed on domestic markets. With so little exploration having been done in Indonesia it is impossible to predict accurately future coal production but much of the key may lie in Maruwai. If development occurs this will open up deposits that are not currently economic.
- The real test of Indonesia's supply capability will come during the next price downturn. If the price dips below $25/tonne FOB many smaller operations will struggle to survive. Therefore, we do not see a significant long term growth in Indonesia exports as coal quality and infrastructure will not permit it. Decline should start after 2010 or if a significant coal price decrease occurs sooner.

In summary, we see the domestic markets of US and Russia enjoying a plentiful coal supply to 2050 but increasing pressure growing in India and to a much larger extent in China, especially post 2030. Importers will face increasing pressure to locate coal which may prompt technological change to happen at faster rate, especially in the area of coal gasification.

7 CONCLUSIONS

In terms of coal outlook, even though the end of fossil fuel usage per se may be more visible in the 2030 – 2050 era, we believe coal remains an integral part of meeting energy needs throughout the 21st century. In light of increasing attention towards limiting greenhouse gas emissions, Clean Coal Technologies will need to be aggressively deployed if coal is not to diminish as a significant energy source in the latter half of the century.

This may include using coal as a potential source for hydrogen technologies and underground gasification which may allow the potential use of some of the 6 or 7 trillion tonnes of coal that may exist in the world (the vast majority of which will not be mined under normal circumstances). Methods to increase mining efficiency and the use of coal mine methane are feasible options to reduce the life-cycle carbon intensity of coal.

The key conclusions of this report are:

- CCT's exist and in conjunction with carbon capture and storage provide several important technical solutions to coal's high carbon intensity. The cost of carbon capture and storage, however, cannot be economically justified in today's energy markets.
- Mapping technologies are advancing and allow the coal industry to identify better coal reserves than in the past, allowing for the more efficient mining of coal. However, progress is slow and largely dependent on oil field technology adapted to coal use. Techniques will help define the mineability
- Mine productivity enhancements are largely established and now key improvements in global productivity will occur from the dissemination of existing techniques, with limited room for improvements in the state-of-the-art.
- Coal mine methane offers to provide some increases in clean energy reserves but is most important as a means of reducing greenhouse gas emissions from coal mining.
- Underground coal gasification is a highly promising, cost effective approach to expand the global coal reserve and the product may be an economic means of limiting greenhouse gas emissions by itself and in conjunction with carbon capture and storage technologies.
- Freights markets are likely to stabilise as the world's bulk carrier fleet sees new build increase overall numbers. Barring unforeseen temporary issues, the fright rates are set to stabilise slightly above historic levels.
- Primary energy demand will grow, in line with GDP, to 2050, averaging 1% annually. Asia will average about 2.5% whilst developed countries see a growth of only 0.5% as energy efficiency increases
- Coal will remain a significant energy source, supplying over 20% of the world's energy needs as nations shift progressively from oil to gas, which expands its share from 21% in 2000 to 34% in 2050
- Without additional policies and measures to reduce emissions, global CO_2 emission is slated to increase to about 40 billion tons in 2050, produced from energy consumption, up by about 2 times levels of 2000. The scale and timing of measures to reduce emissions will impact coal demand and the role of CCT in coal consumption.

Coal's share of energy markets will rise gradually to about 2025 and then decline slowly to 2050. However, we feel that future policies to limit greenhouse gas emissions and potential supply shortages post-2030, will prompt greater research into clean technologies that may create a decline in coal use, at least in the traditional sense

The key to successful CCT coal use is, in our opinion, the utilisation of coal that cannot be mined economically by conventional means or coal that is too low a quality to be sold on export markets.

European Commission

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